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DEPARTMENT OF THE INTERIOR
HUBERT WORK, SECRETARY
BUREAU OF MINES
H. FOSTER BAIN, DIRECTOR

CENTRAL DISTRICT BITUMINOUS COALS AS WATER-GAS GENERATOR FUEL

BY

W. W. ODELL and W. A. DUNKLEY

THIS BULLETIN REPRESENTS WORK DONE UNDER A COOPERATIVE AGREEMENT
BETWEEN THE BUREAU OF MINES, DEPARTMENT OF THE INTERIOR,
THE STATE GEOLOGICAL SURVEY DIVISION OF THE STATE
OF ILLINOIS, AND THE ENGINEERING EXPERIMENT
STATION OF THE UNIVERSITY OF ILLINOIS

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CONTENTS.

Page.

Introduction ... 1
  Purpose of investigation ... 1
  Scope of investigation ... 2
  Previous work ... 2
  Limitations and advantages of bituminous generator-fuel ... 3
General principles of water-gas manufacture ... 3
  Blue gas ... 3
    Effect of time of contact and temperature ... 5
    Blasting fuel with air ... 8
  Reactions in carburetor and superheater ... 12
    Kind of oil ... 13
    Temperature of checker brick ... 15
    Spacing and condition of checker bricks ... 16
      Intimacy of contact ... 17
      Time of contact ... 18
      Effect of checkering on temperature of gases being fixed ... 19
      Effect of checkering on temperature of stack gases ... 19
      Effect on internal resistance of set ... 20
      Decreased velocity of gas ... 20
      Effect on intimacy of mixture of blast gas with secondary air ... 20
    Quality and quantity of blue gas ... 20
    Pressure ... 21
    Efficiency of the oil spray ... 22
Application of principles to practical operation with low-volatile fuels ... 22
  Maintenance of a hot generator ... 23
    Air blast ... 24
    Steam run ... 24
    Condition and depth of fuel bed ... 26
    Operating cycle ... 27
    Up runs and down runs ... 29
    Cleaning the fire ... 29
  Carburetion of gas ... 30
Changes brought about by the use of bituminous fuels ... 32
  Size of coal ... 32
  Exposed surface of fuel ... 32
  Characteristic properties of coal and coke ... 33
  Effect of coking properties ... 33
  Quality of blue gas and blast gas ... 34
  Effect of carburetor and superheater ... 36
    Heat balance ... 36
    Deposits in checker chambers ... 36
  Effect on oil cracking ... 36
  Smoke production ... 36
  Ash and clinker formation ... 37
  Effect on purification ... 37

Page.
Usual methods of operating with bituminous coal fuel........ 37
  Heat balance and cycle........ 37
    Determination of operating cycle........ 41
  Coal fuel in the generator........ 42
    Arching and caking........ 42
  Control of clinker........ 43
  Prevention of sticking of valves by tar deposits........ 44
  Reduced capacity with coal fuel, with the usual operating methods........ 45
  Fuel and oil economies........ 46
Selection of Streator plant for experiments........ 47
  Equipment of plant........ 48
  Preparation for experiments by checking apparatus........ 49
  Gas-analysis apparatus and methods........ 50
  Sampling........ 51
Experimental procedure........ 52
  Cooperation of gas makers........ 53
  Use of coal and coke mixtures........ 54
  Control of arching and caking in the generator........ 56
  Reduction of capacity with coal fuel, with the usual operating methods........ 57
  Air purge........ 57
  Smoke prevention........ 58
  Control of clinker........ 60
  Selection of coal........ 61
Blow-run method of operation........ 62
  Effects on generator conditions........ 62
  Effects of blow run on composition of finished gas........ 64
  Effects of blow run on carburetor and superheater........ 66
  Effects of blow run on fuel and oil economy........ 68
  Comparative efficiency of oil cracking with coke and coal fuel........ 71
  Effect on capacity........ 62
  Use of coal and coke mixtures with the blow run........ 73
Operating results at Streator........ 75
  Coals used in tests........ 75
  Sulphur in gas........ 77
Use of bituminous-generator fuel in plants other than Streator........ 78
Suggestions for operating with coal fuel........ 80
By-products........ 83
  Tar........ 83
  Ammonia........ 85
Design of water-gas apparatus........ 86
Economic significance of the use of bituminous coal as generator fuel........ 86
  Sulphur content as a limiting factor........ 87
Use of coals from other districts as generator fuel........ 87
Summary and conclusions........ 87
Publications on gas producers and industrial gases........ 88
  Publications available for free distribution........ 88
  Publications that may be obtained only through the Superintendent of Documents........ 89
Index........ 90

TABLES.

Page.

TABLE 1. Experiments with water vapor and charcoal........................ 4
2. Decomposition of steam by charcoal at 1,100° C.................. 5
3. Composition of a mixture of CO and CO_2 when in equilibrium with coke under a pressure of one atmosphere........................ 6
4. Rate of formation of CO from CO_2 and coke.................... 6
5. Average composition of blast gas from coke and bituminous coal... 35
6. Analysis of blue gas sampled at generator lid.................... 35
7. Practice at five water-gas plants............................ 47
8. Water-gas operation with mixtures of coal and coke as generator fuel.. 55
9. Typical analysis of blue gas produced with coal fuel, with and without the blow-run cycle............................ 63
10. Analyses of blue gas produced during successive runs between coalings.. 63
11. Composition of finished gases.............................. 65
12. Typical results showing the effects of the blow-run method of operating.. 67
13. Analyses of blow-run gas—successive runs.................... 68
14. Oil efficiencies with coal and with coke fuel.................. 72
15. Conditions and operating results with various coals in the Streator plant.. 74
16. Analyses of coals used in Streator tests...................... 76
17. Operating conditions and results with bituminous generator fuel in plants other than Streator........................ 79
18. Differences in the composition of water-gas tars................ 85

ILLUSTRATIONS.

Page.

FIGURE 1. Carbon dioxide (CO_2) in gases sampled at generator lid during blast and run period.................................... 9
2. Staggered checkering.................................... 18
3. Flue checkering.. 18
4. Loss of time due to operation of valves...................... 28
5. Effect of time of contact and temperature on oil-cracking efficiency.. 31
6. Effect of change in quantity of steam on composition of blast gases.. 39
7. Fuel spreader.. 44
8. Apparatus for sampling gas at generator lid.................. 51
9. Effect of percentage of coal in generator fuel-mixture on capacity of set.. 56
10. Variation of gas made during run as determined from rise of relief holder during successive 15-second intervals.............. 74
11. Relation of sulphur in coal to hydrogen sulphide in unpurified carbureted gas.. 78

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CENTRAL DISTRICT BITUMINOUS COALS AS WATER-GAS GENERATOR FUEL.

By W. W. ODELL and W. A. DUNKLEY.

INTRODUCTION.

PURPOSE OF INVESTIGATION.

About two-thirds of the manufactured gas supplied to the public by the gas plants in the Illinois district is carbureted water gas. The leading generator fuel is coke, made in by-product coke ovens or in retorts, chiefly from eastern gas coals. During the fall and winter of 1917–18, when the demand for coke by war industries and the restrictions of the Fuel Administration in connection with the transportation of coke from eastern States made it almost impossible for many gas companies to obtain their coke requirements, several water-gas plants had to use bituminous coal as generator fuel. Many operating difficulties were encountered, some of which were solved more or less satisfactorily in different plants. A number of plants attacked the problem rather blindly because facilities for making tests were lacking and because technical men were too busy with labor and supply problems to study thoroughly the conditions involved or to ascertain what other plants had done with this fuel. It was therefore with the hope of assisting the gas industry during this critical period, and of promoting the use of Central District coals for gas making, that the Illinois Mining Investigations, a joint agency of the U. S. Bureau of Mines, the University of Illinois, and the Illinois Geological Survey Division undertook the tests discussed in this paper.

This report was compiled under the auspices of a technical committee appointed by Gov. Frank O. Lowden to promote the use of Central District coals in gas manufacture as a war measure. This committee included the following representatives of the various agencies concerned: U. S. Bureau of Mines, E. A. Holbrook and W. W. Odell; Illinois Gas Association, C. W. Bradley and R. B. Harper; University of Illinois, Dean C. R. Richards, Prof. S. W. Parr, and Prof. H. H. Stoek; State Geological Survey Division, F. W. De Wolf, G. H. Cady, and W. A. Dunkley. F. W. De Wolf was chairman of the committee and E. A. Holbrook was secretary.

SCOPE OF INVESTIGATION.

The field of investigation was naturally divided into the following parts: (1) Study of the practice already developed and the difficulties encountered; (2) development, if possible, of operating methods that would obviate these difficulties; (3) testing various coals of the Central District to determine which might be considered for this purpose; and (4) study of some of the technical conditions involved in the manufacture of water gas from bituminous coals.

The first part of the investigation comprised collecting and summarizing the operating data by correspondence and by visits to several plants. The information obtained, which was published by the Illinois Geological Survey Division in Bulletin 22 of the cooperative mining series, formed a basis for the second part of the investigation, the development of practical methods to obviate the difficulties that had been experienced. It was decided that this work could not be done successfully except on a commercial scale. The Public Service Co. of Northern Illinois offered the facilities of its Streator gas plant for these experiments. The work at Streator extended over a period of several months. A preliminary report, dealing chiefly with the operating methods worked out at Streator, has been published as Bulletin 24 of the cooperative mining series by the Illinois Geological Survey Division. The purpose of the present paper is to discuss, in some detail, the principles involved in water-gas manufacture as they apply to the use of bituminous generator fuel; and to discuss in more detail the results obtained in the Streator tests and the application in other plants of the operating methods developed.

PREVIOUS WORK.

Study of the literature of gas manufacture brings to light few, if any, records indicating the successful use of bituminous coal in water-gas manufacture, but conversations with gas manufacturers justify a belief that considerable unreported work has been done in individual plants from time to time. The few experiments that had been made probably convinced operators that numerous difficulties were to be expected when bituminous coal was used, and as long as coke and anthracite were available at fairly reasonable prices there was little incentive for them to experiment with bituminous coal. However, as the war developed increasingly critical conditions in the fuel industry, several operators turned their attention to the possibilities of using bituminous coal in water-gas plants, and when the work reported in this paper was undertaken, several such plants had been operating two or more months with coal fuel.

LIMITATIONS AND ADVANTAGES OF BITUMINOUS GENERATOR FUEL.

There are limitations to the use of a high-volatile fuel in water-gas generators, inasmuch as water-gas sets are designed for low-volatile, high-carbon fuels. When coal is used *under the same operating conditions as for coke fuel*, the daily production capacity is considerably reduced; hence the use of bituminous coal for this purpose has been limited to such plants as did not need to be operated at full capacity. The difference in the cost of coal and coke has been very great in some parts of the country, and gas manufacturers in these regions, with plants not operating at full capacity, have found it decidedly advantageous to use coal fuel.

GENERAL PRINCIPLES OF WATER-GAS MANUFACTURE.

The manufacture of carbureted water gas is essentially a chemical process based upon chemical reactions, some of them simple and easily understood, others complex and not so easy to understand. The process may be considered logically in two parts: First, the formation of the uncarbureted water gas, so-called blue gas; and, second, the enrichment or carbureting of this gas to the quality desired for illuminating purposes.

BLUE GAS.

Uncarbureted water gas (blue gas) consists chiefly of hydrogen (H_2), carbon monoxide (CO), and carbon dioxide (CO_2) when high-carbon, low-volatile fuels, such as coke or anthracite coal, are used. It is formed by passing steam (H_2O) through an incandescent bed of fuel. The amount and composition of gas formed per unit of time depend upon the nature of the fuel, the rate at which the steam passes through the fuel, and the temperature of the fuel at the time the process is taking place. The chemical reactions occurring under varying conditions have been studied by a number of investigators, and the results of these studies will be summarized here to assist those readers that may not have these principles clearly in mind.

The following chemical equations show the principal reactions taking place in a water-gas generator during the steaming period or "run." After each equation, the heating value per cubic foot (corrected to standard conditions) of the total gas formed in the reaction is given:

	B. t. u. per cubic foot.
1. $C+2H_2O=CO_2+2H_2$	217
2. $C+H_2O=CO+H_2$	325
3. $CO_2+C=2CO$	324

Two of the three gases produced by these reactions—CO and H_2—are combustible, and their heating values per cubic foot are nearly alike. The other gas, CO_2, is not combustible and its presence in water gas is undesirable. The quantity of CO_2 present in water gas can be controlled when the generator reactions and their practical application are well understood.

Consideration of the heat of combustion of the gas produced by each of these reactions indicates that equation 1 is an undesirable reaction. Equation 3, however, represents a secondary reaction that takes place when the CO_2 formed in reaction 1 has an opportunity to react further on hot carbon, the time of contact, the concentration of the reacting gases, and the temperature of the fuel bed being the factors that control the extent to which this reaction takes place. When all the CO_2 formed according to equation 1 is converted into CO as in equation 3, the resulting product (considering equations 1 and 3 together) is a mixture of equal volumes of H_2 and CO, or the equivalent of reaction 2. It is desirable in the practical operation of water-gas generators to produce the conditions most favorable for reaction 2 or its equivalent, and at the same time the least favorable conditions for reaction 1. The favorable conditions are: Intimate contact of the steam with the incandescent fuel, a high temperature in the fuel bed, and a desirable time of contact corresponding to this temperature. The reverse of these conditions: Imperfect contact of short duration and low temperatures in the fuel bed favor reaction 1.

All of these reactions may be, and usually are, occurring simultaneously in different parts of the fuel bed in practical operation. They have been more or less thoroughly studied under controlled conditions in the chemical laboratory.

TABLE 1.—*Experiments with water vapor and charcoal.*[a]

Temperature.		Gas velocity.	$\frac{1}{\text{vel.}}$	Constituents.				Composition of dry gas.		
°C.	°F.			CO_2.	CO.	H_2.	H_2O.	CO_2.	CO.	H_2.
		Cu.ft. per sec.		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
674	1,245	0.0318	31.44	3.84	0.63	8.41	87.12	29.8	4.9	65.3
758	1,396	.0636	15.72	9.23	2.67	22.28	65.82	27.0	7.8	65.2
838	1,540	.1158	8.64	12.11	7.96	32.77	47.15	22.9	15.1	62.0
861	1,582	.1870	5.35	13.33	11.01	36.48	39.18	21.9	18.1	60.0
954	1,749	.2224	4.50	5.66	32.70	44.43	17.21	6.8	39.5	53.7
1,010	1,850	.2171	4.60	1.45	48.20	47.30	3.02	1.5	49.7	48.8
1,060	1,940	.3460	2.89	1.25	46.31	48.84	3.68	1.3	48.1	50.6
1,125	2,057	.3990	2.51	.60	48.34	50.73	.303	.6	48.5	50.9

[a] Columns 2, 4, 9, 10 and 11 are computed by the authors.

Table 1[1] by Harries shows the effect of the temperature on the decomposition of water vapor in the presence of carbon (charcoal). Water vapor was passed over heated charcoal and the composition of the resulting gas was determined. The experiment was on a laboratory scale. It will be noted that as the temperature is increased more water vapor is decomposed. Simultaneously there is an increasing percentage of CO and a decreasing percentage of CO_2 in the gas produced, in spite of the fact that the time of contact at the higher temperature was much shorter. Unfortunately Harries does not state the capacity of his apparatus, hence it is impossible to calculate the absolute time of contact; however, the relative contact time is indicated in column 4 as the reciprocal of the velocity.

---

[1] Harries, [Decomposition of water vapor in the presence of carbon]: Jour. Gasbel., Jahrg. 37, 1894, p. 82.

The above table represents results obtained with charcoal as fuel. Other forms of fuel, such as coke and coal, decompose steam with different reaction velocities. Although charcoal decomposes water vapor more rapidly than does coke or some other fuels, the table is characteristic of the effects of temperature on the production of water gas and shows the importance of maintaining a high temperature in the fuel bed of a water-gas generator during the steaming period.

Table 2[2] shows the effect of the time of contact on the decomposition of steam and on the composition of the gases formed when the temperature remains constant. The results were obtained by passing steam over heated willow charcoal.

TABLE 2.—*Decomposition of steam by charcoal at 1,100° C.*

Time of contact in seconds, *t*.	$\frac{1}{t}$.	Composition of gas (per cent).						Composition of dry gas (per cent).			
		CO_2.	CO.	H_2.	CH_4.	H_2O.	Total fixed gases.	CO_2.	CO.	H_2.	CH_4.
6.92	0.1444	0.0	50.5	47.3	1.3	0.9	99.1	0.0	50.95	47.75	1.31
5.62	.1778	.1	50.1	48.1	.8	.9	99.1	.1	50.60	48.50	.80
3.37	.2968	.3	43.3	43.4	.7	12.3	87.7	.34	49.40	49.46	.80
1.773	.5630	.4	39.6	39.0	.2	20.8	79.2	.50	50.00	49.25	.25

It will be noted that as the time of contact of the steam with the heated carbon (charcoal in this case) decreases, the per cent of CO_2 increases and the per cent of CO decreases. In other words, as the time of contact decreases, the reaction of equation 1 ($C+2H_2O=CO_2+2H_2$) becomes increasingly prominent. The amount of steam decomposed increases as the time of contact increases, the decomposition being almost complete with five seconds contact.

EFFECT OF TIME OF CONTACT AND TEMPERATURE.

The effect of the time of contact and the temperature on the relative percentages of CO_2 and CO is made more evident by a further consideration of the reactions affecting these two constituents. It has been pointed out that when CO_2 formed by the reaction of equation 1 has further opportunity to react with glowing carbon the reaction of equation 3 ($CO_2+C=2CO$) takes place if the time of contact and temperature are favorable. Therefore the reactions of equations 1 and 3 together are equivalent to the reaction of equation 2 ($C + H_2O = CO + H_2$), as stated. Thus, when the gases from the water-gas generator are analyzed, it is impossible to say how much of the carbon monoxide present was formed by the reaction of equation 2 or by the combined reactions 1 and 3; however, the conditions affecting the final result are much the same as shown in Table 3.[3]

---

[2] Clement, J. K., Adams, L. H., and Haskins, C. N., Essential factors in the formation of producer gas: Bull. 7, Bureau of Mines, 1911, p. 42.

TABLE 3.—*Composition of a mixture of CO and CO_2 when in equilibrium with coke under a pressure of one atmosphere.*

Temperature.		Per cent CO.	Per cent CO_2.
°C.	°F.		
900	1,652	83.2	16.8
1,000	1,832	94.5	5.5
1,100	2,012	98.1	1.9
1,200	2,192	99.4	.6
1,300	2,372	99.7	.3

This table shows the effect of temperature on the percentages of CO_2 and CO which can exist in equilibrium with hot coke. It will be noted that as the temperature is increased, more of the CO_2 is reduced by the coke to CO, until, in the neighborhood of 1,300° C., practically all of the CO_2 has been reduced to CO. It should be borne in mind that the time of contact of the gases with the hot carbon has not been considered here. All the time needed to effect an equilibrium has been allowed. The percentages of CO are the highest possible at the given temperatures, regardless of the length of time allowed. Experiments have shown that at the lower temperatures the reduction of CO_2 to CO according to equation 3 ($CO_2 + C = 2CO$) proceeds very slowly. For example, when CO_2 was passed through coke heated to 900° C. only 13 per cent of CO was formed with 80 seconds contact, while 142 seconds contact were required to produce 27.6 per cent of CO. Table 4 shows the effects of the time of contact on this reaction at various temperatures.

Time is an important factor in all chemical reactions, and its relation to the reactions in a water-gas generator should be well understood. In Table 4 are shown the effects of changes in time of contact and in temperature.

TABLE 4.—*Rate of formation of CO from CO_2 and coke.*

AT A TEMPERATURE OF 900° C. (1,652° F.).

Time of contact, seconds.	Per cent of CO observed.
142.0	27.6
80.2	13.1
43.9	9.4
16.1	4.9
9.6	2.6
3.7	.8

---

[3] Clement, J. K., Adams, L. H., and Haskins, C. N., work cited, p. 50.

AT A TEMPERATURE OF 1,000° C. (1,832° F.).

123.2	78.4
80.25	64.4
33.25	52.9
18.72	32.0
6.37	13.9
4.1	11.5
3.07	9.2
1.98	6.3

AT A TEMPERATURE OF 1,100° C. (2,012° F.).

90.0	97.1
29.92	85.4
13.2	66.1
6.765	55.6
3.198	31.7
1.784	30.4
1.66	24.0
1.59	22.1
1.462	21.4
0.962	13.3

AT A TEMPERATURE OF 1,200° C. (2,192° F.).

18.92	98.9
12.7	97.8
8.25	95.3
2.402	68.5
1.582	43.9
1.08	33.5

AT A TEMPERATURE OF 1,300° C. (2,372° F.).

8.86	99.9
4.149	97.9
2.1	93.2
1.13	83.4

Note.—The percentages of CO given in Table 2 do not represent the percentage of CO in the finished gas. Reaction 3 is considered by itself in this table and the CO shown is the amount produced when CO_2 is passed through incandescent coke with the time of contact and at the temperatures given.

In the practical operation of a water-gas machine, obviously only a few seconds at most can be allowed for the reactions to take place in the generator. Since at the lower temperatures a prolonged time of contact is necessary and at higher temperatures the reactions take place almost instantaneously, the necessity for maintaining high temperatures in the generator is evident.

When reactions 1 and 3 are considered together and a high fuel temperature is assumed, the resulting products of the reactions are chiefly CO and H_2, as expressed by reaction 2. The amount of CO_2 present in water gas then depends on the time the gases are in contact with the glowing coke, as well as upon the temperature of the coke. In other words, at high temperatures and with a fuel bed of sufficient depth, reaction 2 or its equivalent takes place, while at lower temperatures or with a short time of contact (exemplified by very low fuel bed and excessive ash accumulations in the generator) more of reaction 1 takes place simultaneously with reaction 2. During the steam run the temperature of the fuel in the generator drops considerably, the reaction velocity, or rate at which the steam and carbon combine to form gas, being decreased simultaneously. Expressed in other terms, more steam passes through the fuel undecomposed as the temperature in the generator decreases. This fact must be given due consideration when an operating cycle is worked out.

BLASTING FUEL WITH AIR.

After the steam run is made, it is necessary to bring the temperature in the generator up to the desired temperature before another run can be made. This is done, in present-day processes, by blasting the fuel with air. Air is a mixture of 20.9 per cent of oxygen (O_2) by volume and 79.1 per cent of nitrogen (N_2). Nitrogen, being an inert gas, does not enter into the reaction. The principal chemical reactions that take place during blasting are as follows:

4. $C+O_2=CO_2$.
3. $CO_2+C=2CO$.

In blasting fuel with air, the oxygen of the air combines with the C to form CO_2 as expressed in reaction 4. All the oxygen of the blasted air combines with carbon (at the usual prevailing temperatures) before it has gone very far through the fuel bed; thus the zone of complete combustion is close to the grates and represents but a small percentage of the fuel bed. As the CO_2 that is first formed passes up through the incandescent fuel, it combines further with carbon to form CO, as in reaction 3 already mentioned. When the blast is started, directly after the steam run, the fuel is not hot enough for the completion of reaction 3 with the usual time of contact that prevails during blasting.

The curves of Figure 1, plotted from analyses made during actual operation, show the effect of changes in temperature of the fuel bed on the CO_2 content of the gases made during the blow and during the run. It is noted that during the blow the fuel temperature increases and the CO_2 content decreases, while during the run the fuel temperature decreases and the CO_2 content of the gas increases. CO is the chief combustible constituent of the blast gases that are burned in the carburetor and superheater by the admission of secondary air. It may be expected from the foregoing that a change from coke to a high-volatile fuel may upset the heat balance in a water-gas set by increasing the amount of combustible gas to be burned by the secondary air in the carburetor and superheater. It is not intended to rep-

ERRATA.

PAGE 9. Figure 1, bottom lettering, "Time of taking blow-run sample, minutes" should read "Time of taking blow and run samples, minutes."

Title to Figure 1, "Carbon dioxide (CO_2) in gases sampled at generator lid during blow-run period" should read "Carbon dioxide (CO_2) in gases sampled at generator lid during blow and run periods."

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resent these reactions as the only ones occurring in a water-gas generator. Other reactions take place to a limited degree in addition to those in the volatile matter that may be present in the original fuel, but they will not be mentioned here, since the prime factors have been given.

Each of the four reactions that have been discussed above is accompanied by a transfer of heat. When reaction 4 takes place it evolves heat—is exothermic. All the other reactions proceed with an absorption of heat and are therefore endothermic.

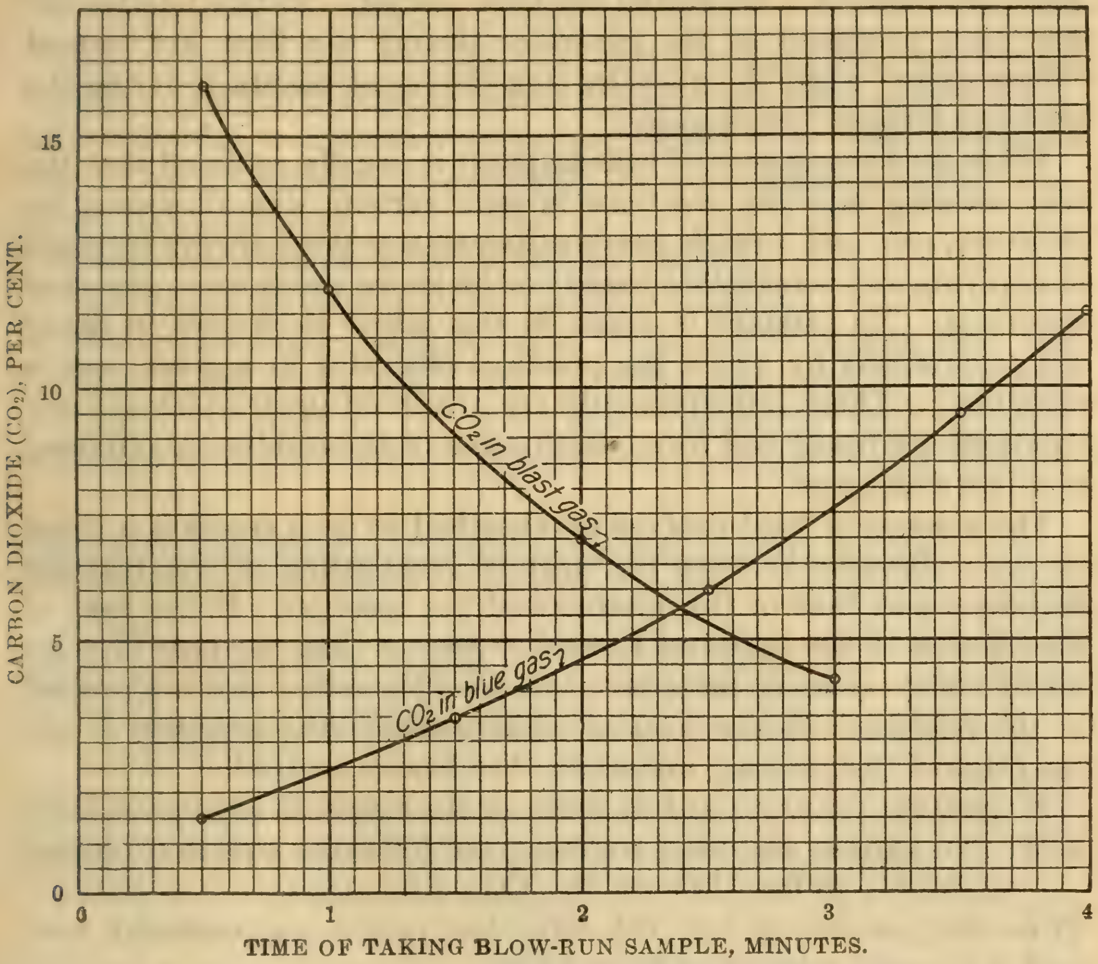

FIGURE 1.—Carbon dioxide (CO_2) in gases sampled at generator lid during blow-run period.

According to these reactions, a definite amount of carbon is consumed in the production of 1,000 cubic feet of blue gas. In practical operation, the amount of fuel required per 1,000 feet is considerably more than that indicated by the equations, since heat losses inevitably occur. These heat losses include—

1. Losses as sensible heat in the blue and blast gases which leave the generator at high temperature.
2. Losses due to unconsumed fuel and sensible heat in the ashes removed from the generator.
3. Losses due to the latent heat of vaporization of water in the fuel.
4. Losses due to radiation and convection from the generator.

5. Losses of heat during lay-over periods when no gas is being made.
6. Losses due to combustion of fuel during fire-cleaning periods.
7. Losses due to the use of excess steam during the steam run.

These losses must inevitably be different in various plants where the kind and size of sets, daily operating time, weather conditions, and fuels are different. A study of the thermal properties of these reactions serves to point out the maximum fuel efficiencies that can be realized in practical operation.

There is some difference in nomenclature in the designation of the gases produced in a set during the blow period. In this publication the gases produced in the generator during the blow are termed "blast gases" while the gases leaving the set at the stack during the blow are termed "stack gases."

While for convenience of calculation it is usually assumed that the fuel entering into the reactions is pure carbon, due allowance for moisture, ash, and volatile combustible matter must always be made in applying any conclusions based on the above reactions to practical operation. No attempt is made in this paper to present in detail the calculations by which the practical efficiency in a given case is computed. Those principles only are presented upon which the calculations are based and from which some of the results are obtained in a particular case.

The amount of heat evolved or absorbed in each reaction is equal to the difference between the heat of combustion of the reacting materials and that of the products of the reaction. If the heat of combustion of the products formed is greater than the heat of combustion of the reacting materials, this is evidence that heat is absorbed in the reaction. If the heat of combustion of the products is less than that of the reacting materials, then heat is evolved.

If equation 2 is expressed in terms of the weight in even pounds by which the various members combine, the following equation results:

$$12 \text{ lbs. } C + 18 \text{ lbs. } H_2O = 28 \text{ lbs. } CO + 2 \text{ lbs. } H_2.$$

From this amount of fuel 755 cubic feet of gas are produced, consisting of equal volumes of H_2 and CO.

The heat of combustion of carbon in the formation of CO is 4,350 B. t. u. per pound of carbon; that of H_2 in the formation of water is 61,523 B. t. u. per pound of H_2. Knowing these values, the amount of heat to be supplied by the generator for reaction 2 can be calculated approximately as follows:

	B. t. u.
Heat of combustion of 2 lbs. of H_2=2×61,523	123,046
Heat furnished by the formation of 28 lbs. of CO=12×4,350	52,200
Heat absorbed	70,846
Assuming that the water was steam at 100 lbs. pressure it has already received 18×1153.9 B. t. u	20,770
The total heat absorbed in the formation of 755 cu. ft. of gas produced according to equation 2 is	50,076

Approximately 100 per cent more steam is actually used in water-gas generation than is shown by the theoretical chemical reaction. This steam, in passing through the fuel bed unchanged, absorbs heat and must therefore be considered when arriving at an absolute heat balance. Likewise, there must be considered the sensible heat of the gases.

The total heat must be supplied by the combustion of fuel in the generator. The amount of heat necessary for the production of 1,000 feet of this gas is:

$(1{,}000 \div 755) \times (50{,}076) = 66{,}300$ B. t. u.

It is estimated that reaction 1 ($C+2H_2O=CO_2+2H_2$) takes place in practice only to the extent of about 5 per cent and reaction 2 ($C+H_2O=CO+H_2$) to the extent of approximately 95 per cent during the run. This is considered, of course, in calculating the fuel consumed during the run.

Reaction 1 is expressed in pounds as follows:

12 lbs. C + 36 lbs. H_2O = 44 lbs. CO_2 + 4 lbs. H_2.

In this instance, the combination of 12 pounds of carbon with H_2O produces 1,133 cubic feet of gas, of which one-third by volume is CO_2 and two-thirds is H_2. The heat balance of this equation, developed after the method employed for equation 2, is as follows:

	B. t. u.
Heat furnished by combustion of 12 lbs. of carbon burning to CO_2 (12×14,544).	174, 528
Heat furnished by the steam (36×1153.9)	41, 540
Total	216, 068
Heat of combustion of H_2 (4×61,523)	246, 092
Total heat to be furnished by combustion of fuel in generator for this reaction	30, 024

A heat balance can be similarly developed for the reactions expressed by equations 3 ($CO_2+C=2CO$) and 4 ($C+O_2=CO_2$).

Reaction 3, expressed in pounds, is:

12 lbs. C + 44 lbs. CO_2 = 56 lbs. CO.

Reaction 4, expressed in pounds, is as follows:

12 lbs. C + 32 lbs. O_2 = 44 lbs. CO_2.

This is the primary reaction taking place in the zone of complete combustion of the generator during the blast. The heat generated by this reaction is:

$12 \times 14{,}544 = 174{,}528$ B. t. u.

Reaction 3 is a secondary reaction and the extent to which it takes place can be determined only by analyses of the gas. The net result of blasting the generator can only be determined when it is known to what extent reaction 3 takes place. Since reaction 4 is the heat-producing reaction, it is evident that the extent to which it must take place during the blow period to supply the requirements of the other reactions and the heat losses which inevitably occur in practical operation will depend upon a number of variables, including the extent to which each of the heat-absorbing reactions occurs. By assuming that each of these reactions occurs in definite amounts, that the fuel contains a definite amount of inert material, that the gas and blast products leave the generator at a given temperature, and that a certain amount of heat is lost by radiation and convection, and in other ways, it is possible to compute what the fuel consumption will be during each phase of operation.

The gases usually leave the generator at or near a temperature of 1,400° F. and when the net result of blasting the generator or the effect of making a steam run is to be estimated, the loss due to the sensible heat of the gases must be considered. Computations based upon certain assumptions and specified conditions have been made by a number of engineers. The coke consumed per 1,000 cubic feet of blue gas made, as computed by Norton H. Humphreys [4] from conditions assumed by him, may be summarized as follows:

	Pounds.
Coke used to form CO and CO_2 during run	17.2
To supply heat carried off as sensible heat	11.0
Consumed during blow	12.6
Total	40.8

In determining the heat losses, especially those due to convection, radiation, and the sensible heat in the gases leaving the generator, some assumptions that are based upon imperfectly worked out data must be made. For example, in computing the heat loss as the sensible heat of the gases, the heat-carrying capacity of these gases at high temperatures must be known. Although various values are given for the specific heats of gases at high temperatures, consideration of the available data leads the authors of this paper to believe that the specific heats taken by Mr. Humphreys may be a little high but are valuable to illustrate the problem in hand.

REACTIONS IN CARBURETOR AND SUPERHEATER.

When gas oil is sprayed into the carburetor on the hot checker brick, it is decomposed or cracked. The final products of decomposition depend on a number of varying conditions. Some of the more important are the following:

1. Kind of oil used.
2. Temperature of checker brick.
3. Spacing and condition of checker brick.
4. Quality and quantity of blue gas in the atmosphere where the oil is being cracked.
5. Quantity of oil cracked per unit of time.

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[4] Humphreys, N. H., Thermal problems for gas engineers: Jour. Gas Lighting, vol. 135, pp. 393–394.

6. Pressure.
7. Efficiency of the oil-spray nozzle.

When some of the conditions affecting the efficiency of oil cracking are changed, some undesirable results are occasionally noted. A study of all the results obtained under varying conditions has led to some interesting deductions and to a better understanding of the reactions occurring in the carburetor and superheater. The chemical and thermal reactions taking place when oil is cracked are more numerous and complicated than the simple reactions taking place during the production of blue gas in the generator. In addition to the reactions of the oil-decomposition products among themselves, there are, under some conditions, reactions between these products and the gases from the generator (blue gas).

When oil is cracked in the usual water-gas process, there are formed gas and varying amounts of carbon, tar, naphthalene, and condensable hydrocarbons. Since it is the object to produce the maximum amount of gas per gallon of oil—consistent, of course, with the quality of gas desired—with a minimum amount of carbon, naphthalene, and tar, the conditions governing the formation of each are of as much importance for the successful operation of a water-gas set as the factors affecting the various constituents of the gas. Some of the latter are discussed here in the order given above.

KIND OF OIL.

The kind of oil used has considerable bearing on the results obtained; hence the specifications on which gas oil is purchased are of interest. It is not uncommon to find oil purchased according to the specific gravity (the Baumé reading), or according to the viscosity and the Baumé test. Some companies fractionate the oil and collect fractions every 100° F. up to 700° F., noting the condition and quantity of the fractions and of the residue. This residue may be all carbon or coke and may represent a small per cent of the original sample, or it may be a heavy oil and represent either a large or a small per cent of the sample. Some specifications limit the amount of residue; others demand a certain uniformity of the quantity fractionating at the different temperatures.

Since the crude oils from different fields are not alike, their distillates are likewise dissimilar. Furthermore, a mixture of a heavy oil and a light oil will produce an oil with an intermediate specific gravity that could not be distinguished by a Baumé hydrometer from an oil of the same gravity with a constant boiling point.

Sherman and Kropp[5] report that the heating value of an oil varies with its specific gravity. They state that the formula:

B. t. u. per pound = 18,650 + 40 (B.—10)[5a] gave results within 1 per cent of the actual on more than 60 oils tested by them. Tests made since by others have shown a similar relation. Attempts have been made to make use of this in grading the various oils, but the B. t. u. efficiency

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[5] Journal of Gas Lighting and Water Supply, Meeting of Dutch Managers.—Report of committee on testing of gas oils: Vol. 115, 1911, p. 543.

[5a] B. is the degree Baumé.

$$\frac{\text{B. t. u. in the gas per gallon of oil used}}{\text{B. t. u. in the oil per gallon}}$$

varies to such an extent that it is impossible to grade gas oils this way.

When consideration is given to the characteristics of the oils from the different fields, it is evident that there is no simple quick test which can be made the basis for assigning the correct value to a particular oil. Some of the known properties of oils, however, are helpful in making a specification or in choosing between two oils of different quality and price.

An oil of high viscosity may cause some trouble in cold weather during unloading and pumping, requiring the use of steam coils. No relation appears to exist, however, between the viscosity and the cracking efficiency of an oil.

In general the fractions resulting from distillation become more valuable for water-gas manufacture as the temperature at which they distil over becomes higher. This is more particularly true when the fractions, which are taken off for every 100 degrees up to 700° F., increase in volume up to that temperature. However, with some oils whose maximum fraction comes off at a considerably lower temperature than 700° F., the volume of the succeeding fractions decreasing rapidly, the high-boiling fractions have been shown to be inferior. The specific gravities of these fractions help to assign a value to an oil. The value of any fraction increases—for a given boiling point—as the specific gravity decreases. When a gas oil of good quality is distilled to a carbon residue, the coke should not exceed 2 per cent.

It is usually considered that the following classes of hydrocarbons in gas oils are valuable for enriching in the order named: (1) Paraffins; (2) olefines; (3) naphthenes; (4) asphaltics; (5) aromatics.

Since the paraffins are the best gas-making oils, such tests as sulphonation or bromination are of value as a means of distinguishing between the amount of paraffins and unsaturated hydrocarbons and aromatics present. A low bromination value indicates a high percentage of paraffins.

A very ingenious method of comparing gas oils was devised in the Peoples' Gas Light Co. laboratories and described in the proceedings of Illinois Gas Association, 1916. By this method, oil is cracked in the laboratory under conditions approximating those in actual practice. By making all the oil tests under the same conditions, and allowing the same time of contact at the same temperatures, comparative results can be obtained. In this article are given the results of tests made on more than a dozen oils, including such tests as specific gravity, degrees Baumé, viscosity, flash point, burning point, distillation results (giving fractions for each 100° F. up to 700° F.), bromine number, B. t. u. per pound, per cent sulphur, and cracking results, which include B. t. u. per gallon, per cent of tar, per cent of gas, per cent of carbon, and B. t. u. efficiency. In addition, a study was made of the effect of changes of temperature on the per cent of carbon, tar, and gas formed, and curves are plotted for the results. Table 12 (see p. 67) shows the effect of cracking oil in different atmospheres, such as nitrogen, carbon monoxide, and hydrogen. The results obtained by the use of this apparatus coincide with the conclusions of other investigators, who have also pointed out the superiority of the paraffin hydrocarbons for carbureting water gas.

The sulphur in the oil varies with the different oils and may be as low as 0.1 per cent or as high as 2 per cent. The value to be put on the sulphur test will naturally depend on the equipment of the plant where the oil is to be used for removing sulphur from the gas. The importance of this test will have to be judged by the plant superintendents, who know their own conditions best. The amount of sulphur in the unpurified carbureted gas is, of course, not directly proportional to the sulphur in the oil, although an increase in the sulphur content of the oil increases the per cent of sulphur in the gas, other things being equal.

TEMPERATURE OF CHECKER BRICK.

Regulation of the temperature of the checkerwork in the carburetor and superheater is essential for efficient oil cracking. The effect of the temperature on the cracking of oils has been studied by several investigators and a number of significant facts have been pointed out. The variety of conditions under which the various experiments were made and the differences in the oils tested often make absolute quantitative comparisons difficult, if not impossible. In general, it may be said that, other conditions remaining the same, the effects of temperatures in the checker chambers on the results obtained are as follows:

1. The candles per gallon reach a maximum between 1,300 and 1,350° F.
2. The percentage of illuminants reaches a maximum between 1,300 and 1,400° F.
3. The per cents by volume of methane and hydrogen increase with increasing temperature.
4. The volume of oil gas increases with the temperature.
5. The per cent of carbon formed from the cracking of the oil increases with the temperature.

6. The per cent of tar formed decreases with increasing temperature.

7. The B. t. u. per gallon of oil increases with the temperatures and quite often the maximum is not reached under 1,500° F.

The above conclusions apply, in general, to temperatures up to 1,600° F., which is about the upper limit of the experiments made, so far as data are available. In plants making gas to a heating-value standard, it would seem, on consideration of the above facts, that the higher the temperature carried the more favorable would be the results. However, the formation of an increasing amount of carbon from the oil, as temperatures increase, and an increasing formation of naphthalene preclude the possibility of operating with temperatures much in excess of 1,400° F. With excessive temperatures, carbon rapidly clogs the interstices between the checker bricks and the offtake connections of the gas set. The naphthalene is carried forward some distance with the gas and, when cooled, is deposited upon parts of the works connections and of the distribution system that are difficult to reach, causing serious stoppages.

It is therefore generally desirable to operate with as high a temperature in the checker chambers as good practice has shown to be consistent with the above facts. Temperatures between 1,300 and 1,400 °F. seem most favorable when the ordinary gas oils are used.

There are many gaseous reactions that take place, or may take place in the checker chambers, between the various products of oil cracking. The reaction velocity is different for the various reactions and is affected by the temperature and other variables. Many of the primary gaseous reactions have been studied by investigators. W. F. Rittman[6] discusses some of these very completely and gives the equilibrium constants for a number of these reactions at various temperatures.

SPACING AND CONDITION OF CHECKER BRICK.

The spacing of checker brick in the carburetor and the superheater is an operating detail that has considerable bearing on the oil cracking efficiency. The bricks absorb the heat produced during the combustion of the blast gas in the checker chambers and give up the stored heat to the oil, oil gas, and blue gas during the run. Increasing the space between the checker brick produces the following results:

1. Decreased number of brick in a shell of given size.
2. Decreased surface exposed for contact with the oil vapor and gas.
3. Decreased quantity of heat stored at any given temperaure.

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[6] Rittman, W. F., Thermal reactions in carbureting water gas. New York, 1914; Thermal reactions of petroleum hydrocarbons in the vapor phase: Jour. Ind. Eng. Chem., vol. 7, 1915, pp. 945–953; Utilization of aromatic hydrocarbons derived from cracked petroleum: Jour. Ind. Eng. Chem., vol. 7, 1915, pp. 1014–1019.

4. Increased per cent of voids or free space. Other things being the same, further results of this change are:

a. Decreased intimacy of contact of the oil vapor and bricks.

b. Increased time of contact.

c. Possible decreased temperature of the gases being fixed in the carburetor.

d. Possible increased temperature of the waste gases at the stack.

e. Decreased internal resistance in the set.

f. Decreased linear velocity of the gas.

g. Decreased intimacy of the mixture of blast gases with secondary air.

All of these variables affect the cracking of the oil. They are closely interrelated, and since in practice it is very difficult so to fix the conditions that one variable at a time can be studied, it follows that present knowledge of the effects to be attributed to each of these variables is very incomplete. In discussing them, therefore, tendencies only can be indicated, and it is quite impossible at the present time to fix the magnitude of the effect to be attributed to each variable.

INTIMACY OF CONTACT.

By the intimacy of contact is meant the thoroughness with which the gas comes in contact with the surface of the bricks. An increase in the spacing decreases this intimacy of contact, and vice versa. Although the extent to which the gas comes in contact with the bricks is of great importance in the practical operation of a water-gas set, yet it is difficult to assign a definite value to this variable for a given set of conditions, for the reason that a change in the spacing of the bricks not only affects the intimacy of contact but produces other changes already mentioned.

The surface of the brick has an effect, be it catalytic or simply a matter of heat transference, or both, on the cracking of the oil, and changes with a change in intimacy of contact. There are many ways of checkering carburetors and superheaters, and with some of these methods the intimacy of contact can be changed without changing the time of contact.

Figure 2 illustrates the usual "staggered" checkering which compels the gas to take a sinuous course in passing through it. With this method of checkering, a change in the spacing of the bricks directly influences the time of contact and other variables.

Figure 3 illustrates checkering in what is known as flue formation. The bricks are not staggered but are laid in such a way as to form numerous flues through which the gas passes. As with the staggered formation, a change in the spacing changes the time of contact;

however, a change from the system shown in Figure 2 to that of Figure 3, using the same number of bricks and the same distance between rows, alters the intimacy of contact without affecting the time of contact of the gas. In changing thus from the arrangement of Figure 2 to that of Figure 3, the intimacy of contact is decreased. This means that during the blasting period the blast gases pass from the stack at a higher temperature and more blasting is required to bring the temperature in the checker chambers up to the desired degree, which results in an increased fuel consumption.

Intimacy of contact can be changed further without affecting the time of contact, gas velocity, and other variables, by changing the size of the bricks. For example, when 2½-inch bricks spaced 4 inches apart are used, the intimacy of contact is not nearly so great as when 1¼-inch bricks spaced 2 inches apart are used, although the time of contact is practically the same in each case.

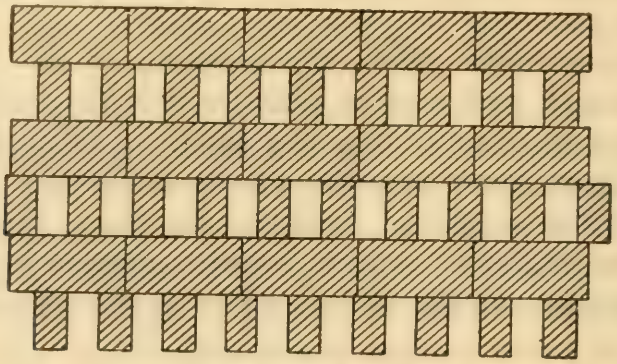

FIGURE 2.—Staggered checkering.

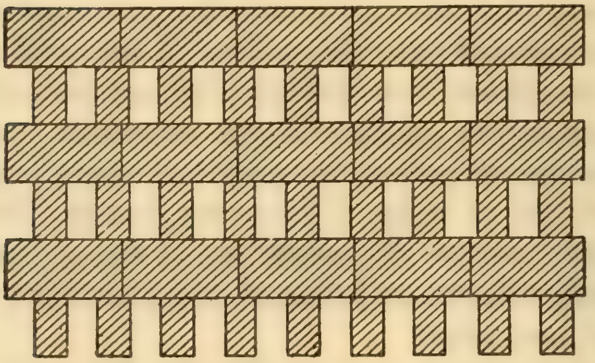

FIGURE 3.—Flue checkering.

TIME OF CONTACT.

The time of contact designated in this paper is the time required for any given molecule of gas to pass through the checker chambers, and may be computed as follows:

I is the time of contact in seconds; S is the total free space in the checker chambers (when checkered) in cubic feet; and V is the volume of the gas in cubic feet flowing through the checker chambers per second.

Then, $I = \frac{S}{V}$.

The time of contact calculated from this formula represents the time the gas is in the checker chambers, but not the time the gas is in actual contact with the bricks.

Available information on this subject seems to be meager, due perhaps to the fact that so many variables, about which little is known, must be considered at the same time. Another reason may be that the time of contact is continually varying during the gas-making period. The make of blue gas during the first half minute of the run may be four times as great as that during the last half minute. Under these circumstances, the time of contact is increasing from the beginning to the end of the make period, while the velocity is decreasing.

Obviously, as the spacing between the bricks is widened the volume of actual free space within the checkerwork increases, and if it be assumed that the volume of gas flowing through the checkerwork in a given time remains the same, it is evident that the time of contact computed as stated above will increase and the gases will remain a longer time within the checkerwork. Time is an important factor affecting the completness of oil-cracking reactions; therefore, *other conditions remaining the same, the longer the time of contact, the more complete the oil cracking.*

When oil is being cracked in a water-gas carburetor, *intimate contact is desired, with a time of contact sufficiently great to gasify the oil.* Too great a time of contact may result in the production of naphthalene or of lamp black.

EFFECT OF CHECKERING ON TEMPERATURE OF GASES BEING FIXED.

A change in the spacing of the checkerwork changes the total volume of brick and consequently the total heat capacity of the checkerwork at any given temperature. Since the heat for fixing the oil gas is derived from the brick, it is evident that with a smaller or a greater amount of stored heat available for this purpose any given volume of gas will be heated correspondingly to a lower or a higher temperature. It has already been pointed out that as the spacing of the checkerwork is widened the intimacy of contact of the gas with the brick surfaces is diminished, and consequently there is less opportunity for the heat of the brickwork to be transmitted to the gas by surface contact. This alone tends to decrease the temperature of the gas, if the quantity of the gas in both cases is the same.

EFFECT OF CHECKERING ON THE TEMPERATURE OF STACK GASES.

The bricks of the checker chambers are heated by the combustion of the generator blast gases when the secondary air is admitted to the carburetor.

The blast gases transmit a portion of their heat to the brick during the blow period. It is evident that any increase in the spacing of the checker brick decreases the number of bricks that can be placed in the space allotted for checkerwork. Consequently, with wider spacing the total volume of brick decreases and with it the total heat storage capacity of the brickwork decreases for any given temperature. Since the brickwork can not absorb so much heat from the blast gases per unit of time, the temperature of the gases leaving the machine will be higher and the loss of sensible heat in the stack gases will be greater, due to the higher temperature now prevailing.

EFFECT ON INTERNAL RESISTANCE OF SET.

When the checkerwork is more widely spaced, the percentage of free space increases, as has been noted, and the internal resistance of the checker chambers to the passage of gas decreases. With given air pressures, available during the blast, more air can be forced through the fire as the internal resistance of the set decreases. This of itself is an advantage if the wider spacing does not adversely affect the other conditions mentioned above.

DECREASED VELOCITY OF GAS.

With increased free space and consequent increased time of contact, the linear velocity of the gases passing through the checkerwork necessarily decreases, since the total volume of gas passing per unit of time is assumed to remain constant.

This change in velocity affects the deposit of dust-like material carried mechanically by the gases passing through the checkerwork. Its further effects on temperature, deposit of carbon, and efficiency of cracking are intimately connected with the time and intimacy of contact, under which heading they have been discussed.

EFFECT ON INTIMACY OF MIXTURE OF BLAST GAS WITH SECONDARY AIR.

In order to obtain complete combustion of the generator blast gases in the checkerwork, it is essential to have an intimate mixture of the gas and the secondary air. This intimacy of mixture is facilitated by the many impingements made by the mixture on the brickwork, and the extent of this impingement decreases as the spaces widen.

QUALITY AND QUANTITY OF BLUE GAS.

The quality of the blue gas, in which atmosphere the oil is cracked, affects the final products in the finished gas. Oil has been cracked in various gas atmospheres on a laboratory scale and the results have been studied. Downing and Pohlman[7] state that at the temperatures usually prevailing in the checker-work, the B. t. u. content per gallon of oil used is greater when the oil is cracked in blue gas of good quality than when the oil is cracked in CO_2, N_2, or CH_4 alone. An increased amount of CO_2 in the blue gas lowers the B. t. u. efficiency of oil cracking. However, it was pointed out that the B. t. u. content of the gas, per gallon of oil cracked, is greatest when there is 20 per cent steam in the blue gas. It seems to be true that the oil cracks better in blue gas of good quality than in that of poor quality, which gives additional incentive to produce the best possible grade of blue gas in the generator. When cracking oil in blue gas of good quality at the usual temperatures—1,300 to 1,400° F.—the quantity of gas and tar is greater and the per cent of carbon formed is less than when the cracking takes place in blue gas of poor quality. During the make period the quantity as well as the quality of blue gas is continually decreasing, while the per cent of excess steam is usually increasing. The efficiency of oil cracking is affected by these factors in opposite directions. As the volume of blue gas decreases during the run, the concentration of the oil gas increases (with the constant input of oil), and the time of contact is correspondingly longer, which tends toward the formation of an increasing amount of carbon. Simultaneously the per cent of steam in the blue gas is increasing, and with it the oil-cracking efficiency is increased, with a diminished tendency to deposit carbon. The degree to which these two opposing factors offset each other depends on a number of other variables; hence, it is difficult to assign definite values to them.

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[7] Downing, R. C., and Pohlman, E. F., Cracking of gas oils in various atmospheres: Gas Jour., vol. 137, 1917, pp. 24–26.

The quantity of oil admitted to the carburetor per unit of time affects the concentration of the gas in the carburetor, as well as the time and intimacy of contact of the oil gas with the checker brick. This, of course, directly affects the yield of gas, tar, and carbon. If oil is added so rapidly that the surface of the top bricks in the carburetor is cooled, owing to the conductivity of the brick being too low to transmit its heat to the surface quickly enough, there is a tendency for distillation, and not cracking, to take place, and the effect is a deposition of a coke-like carbon on these bricks. This tendency is greater with some oils than with others. In fact, the quality of the oil is often a more important factor than the rate of oil input in governing the quantity of tar, carbon, and similar substances formed.

PRESSURE.

All gaseous reactions are affected in some degree by pressure. Rittman has shown [8] that when in the cracking of oils pressure is increased to higher than atmospheric the following results occur: First, an increased amount of carbon is formed; second, an increased volume of methane; and third, a decreased volume of illuminants.

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[8] **Rittman, W. F., Thermal reactions in carbureting water gas.** New York, 1914.

The temperature of cracking and the extent of increase of pressure affects the results just given. Although slight changes in pressure in the checker chambers of a water-gas set do not alter the results to any extent, the tendencies should be noted.

EFFICIENCY OF THE OIL SPRAY.

The efficiency of oil spraying is of great importance in water-gas manufacture. The spray nozzle usually needs more attention than it gets. When the carburetor is checkered, great care is usually taken to have the last course (top course) of checker bricks at such a height that the nozzle can distribute oil uniformly over the entire top course. However, the nozzles themselves are not always tested to see that they are performing as desired. When a spray spreads the oil too heavily in certain spots, the result is that the surfaces of the bricks receiving the most oil become cooler than the adjacent bricks. Distillation takes place to a considerable degree around these cooler bricks, and a deposit of carbon forms that increases with time. While this part of the checkering is being choked with carbon, the adjacent bricks may become so hot that they fuse and run together. When nozzles of proved efficiency are not in use, a change of nozzle from day to day will help somewhat in overcoming this undesirable result.

APPLICATION OF PRINCIPLES TO PRACTICAL OPERATION WITH LOW-VOLATILE FUELS.

In the foregoing section, the operating principles discussed have been general, and although their interrelations have been dealt with to a certain extent, it remains to be shown how they are affected by the changes and conditions of practical operation.

Most of the operating variables of a water-gas plant are interdependent; in other words, a change in one affects many others. That this is true has been realized by most operators, some of whom attempted to study the effects of various changes, considered the problem bewildering, and stopped discouraged. R. P. Harper has listed 289 variables and indicated their interrelations in his article in the American Gas Engineering Journal.[9] Some of these variables are listed below, although no attempt is made to enumerate all of them.

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[9] Harper, R. P., Gas machine factors involved in the manufacture of carbureted water gas: Am. Gas Eng. Jour., vol. 110, 1919, pp. 312-316, 320-324.

a. Blast.
  Amount of air blown in total blasting time.
  Quality—Dry or moist.
b. Steam.
  Quality—Dry or wet.
  Quantity per unit of time—Dependent on variable steam pressure as well as intentional change in valves.
  Total length of steam run.
c. Fuel.
  Kind—Physical and chemical properties.
  Size—
d. Depth of fuel bed.
  Amount charged at a time.
  Frequency of charging.
e. Cycle.
  Duration of blow.
  Duration of steam run.
f. Proportion of up and down runs.
g. Clinker and ash in generator.
h. Kind of oil used and time of admission into carburetor.
i. Condition and spacing of checker bricks.
j. Efficiency of oil spray.
k. Temperatures maintained in carburetor and superheater.
l. Quality and quantity of blue gas made in generator during run.
m. Combinations of the above variables.

In attempting to control and regulate the operating variables, it is essential from a practical viewpoint to achieve the following:

1. Make the maximum amount of standard quality gas possible per day or running hour.
2. Use the least amount of generator fuel possible per 1,000 cubic feet of gas made.
3. Use the least amount of steam possible per 1,000 cubic feet of gas made.
4. Use the minimum amount of oil for carbureting per 1,000 cubic feet of gas made.
5. Accomplish these four purposes with the lowest possible operating and maintenance costs.

The accomplishment of these results depends, among other things, upon the maintenance of suitable temperatures in the generator and checker chambers. The various processes must be so arranged that all the chambers attain their operating temperatures at the same time. A temperature balance between the various parts of the set must be created and preserved within reasonable limits at all times during operation.

MAINTENANCE OF A HOT GENERATOR.

The maintenance of a hot generator is one of the first problems to be solved in applying theory to practical operation. Tables 3 and 4 (see pp. 5 and 6) show the necessity of maintaining high temperatures in the fuel bed for efficient operation.

When endeavoring to preserve the desirable high temperature in the fuel bed, the variables affecting this temperature must be given due consideration. Some of the prime factors on which it depends are as follows:

1. Air blast.
    - Duration of blasting period.
    - Quantity of air per minute.
    - Condition of air—dry or moist.
2. Steam run.
    - Duration of steam run.
    - Quantity of steam per minute.
    - Dry or wet steam.
3. Condition and depth of fuel bed.
    - Frequency of charging.

AIR BLAST.

Since air blasting accomplishes the double purpose of heating the fuel in the generator and heating the checker brick in the carburetor and the superheater, it is well to keep in mind the conditions governing reactions 4 ($C+O_2=CO_2$) and 3 ($CO_2+C=2CO$) given on page 8.

The length of the blasting time depends, of course, on the amount of fuel in the generator and the quantity of air per minute that can be forced through the bed with the available blast. The zone of complete combustion is, normally, that part of the fuel bed directly over the grates, possibly not more than a foot in depth. The thermal reactions taking place above this zone are endothermic. (See reaction 3 ($CO_2+C=2CO$) on page 3.) Since the fuel in the upper part of the generator is not heated by direct combustion of the fuel but chiefly by convection, it is evident that, other things being equal, the rate of the blast has considerable influence upon the regulation of temperature in the fuel bed. A prolonged blast, with a low blast pressure, is usually not so desirable as a high blast pressure with a short blasting period. This is true not only on account of the time saved with the shorter blasting period, but also on account of the better distribution of heat through the fuel bed.

Moisture in the air blast also has a marked effect on the temperatures in the generator. Study of the endothermic reactions 1 and 2, on page 3, clarifies this point and emphasizes the desirability of dry air; hence great care is usually taken that the exhaust steam from the turbine is not drawn into the fan or the blower.

STEAM RUN.

With a properly timed cycle, as much heat is abstracted from the generator fuel bed during the run as was stored in it during the blow. The actual duration of the steam run is governed by the quantity of steam admitted per unit of time. It is desirable to use steam at such a rate that the length of the run is little if any greater than the length of the blast period, when average blast pressure is used. Decreasing the quantity of steam and increasing the steaming time increases the time of contact both in the generator and fixing chambers, which may or may not be advantageous, according to existing conditions.

The steam should be dry or as free from moisture as possible. Water that condenses in the main steam-supply lines can be removed by a steam separator. Every pound of water entering the generator as such absorbs approximately 971 B. t. u. in changing from water at 212° F. to steam at the same temperature.

In order to maintain the desired fuel temperature in the generator, the quantity of air and steam must be correctly proportioned. This is best accomplished by closely studying the ill-effects of an excess either of air or of steam. Consider, for example, a fresh fire operating with a 3-minute blast and a 3-minute steam run, with insufficient steam. It is apparent that under these conditions, in which not enough steam is added during the run to absorb the heat stored in the generator during the blast, the generator fuel will become hotter as the day proceeds. This naturally results in the generation of more combustible gas (reaction 3 being more complete at high temperatures) during the blast, which, if burned in the carburetor and superheater, increases their temperatures to an undesirable degree. Even if the temperature in the checker chambers is reduced by using an excess of carburetor air blast, the waste of heat in the blast gases is excessive and involves the consumption of additional generator fuel per 1,000 cubic feet of gas made. Moreover, the excessive temperature in the generator brings about a more complete fusion of the ash and occasionally a very hard clinker may be formed.

Operating with the same cycle but using an excess of steam, or—what amounts to it—an insufficient amount of air blast, the opposite effects are noted. The generator temperature becomes so low that the CO_2 formed in the zone of complete combustion during the blow does not combine further with carbon to form CO as in reaction 3 on page 8. Insufficient combustible gas is therefore produced during the blast period to furnish the necessary heat for the carburetor and superheater and the temperatures in these chambers gradually decrease. This results in improper cracking of the oil as evidenced by oil showing at the seal pot and by an increased oil consumption per 1,000 cubic feet of gas made. If the generator becomes cooler as the day proceeds, the clinker is not usually hard; in some cases there is no clinker, but an accumulation of ash. The blue gas is not so rich when this excess of steam is used. Tables 1, 3, and 4 show that, at the reduced temperatures now prevailing in the generator, more CO_2, less CO, and an increased amount of undecomposed steam will be present in the blue gas. This fact is utilized in some plants to determine the efficiency of operation. To do so, the finished gas is tested for CO_2. An increase over a fixed standard, which is considered to be a satisfactory one, is usually taken to denote the use of an excessive amount of steam during the run.

CONDITION AND DEPTH OF FUEL BED.

The condition of the fire in the generator not only affects the temperature in the generator, but the output or "make" as well. The accumulation of ashes leaves a decreasing space for incandescent fuels, hence the last runs before cleaning the fire (under usual operating conditions) are made with less incandescent fuel than earlier in the day. Since the same cycle is usually employed throughout the day, it is obvious that the quality and quantity of the gas produced are affected as already stated. This is especially the case when an inferior fuel containing a high per cent of ash is used.

When too many runs are taken off a charge, that is, when the charging interval is too long, the fuel in the generator is too low for a considerable part of the day. This decreases the volume of incandescent fuel in the generator, and, like the accumulation of ash in the generator, results in a decreased quality and quantity of blue gas being made during the run. When the charging interval is long and the ash has accumulated rather extensively, the results are: A marked decrease in the make per run, an increased steam consumption per 1,000 cubic feet of gas made, and an increased per cent of CO_2 in the finished gas.

To summarize, it may be said that since a high temperature in the generator fuel bed is necessary for efficient operation, the following facts should be kept in mind:

1. As deep a fuel bed as possible should be maintained in the generator to permit a greater quantity of steam to be decomposed and to allow a longer time of contact of the gases with the incandescent fuel.
2. Charges should be made often enough to prevent the fuel in the generator from becoming excessively low, for the same reason as in 1.
3. An excessive amount of ashes or clinker should not be allowed to accumulate in the generator.
4. The air blast should be as free from moisture as possible.
5. The maximum amount of available air-blast pressure should be used at the generator when maximum capacity is desired, thereby obtaining the maximum introduction of air to the fire per unit of time.
6. The use of an excessive amount of steam should be carefully avoided during steam runs. This precaution not only aids in maintaining the proper temperature in the generator, but helps to keep the fuel consumption per 1,000 feet of gas down to a minimum.

7. When there is a tendency for steam to condense in the steam lines, the use of a steam separator is advisable.

8. The steam used during the run should be as dry as possible.

9. Leaky steam valves permitting up steam to enter the generator when a down run is being made, or vice versa, should be watched for and corrected when found. Leaky hot valves that permit steam to by-pass the fire should also be avoided.

10. Dirt and carbon should not be allowed to accumulate under the gates of the hot valves.

OPERATING CYCLE.

The selection of the best operating cycle is an individual problem for each operator. Since the quantity of air and steam available per unit of time varies to a considerable degree in different plants, it is obvious that a fixed standard, such as a 3-minute blast and a 4-minute run, or a 4-minute blast and a 3-minute run, can not be specified for all cases. Since steam produces better gas at the higher temperatures, a very short operating cycle would be desirable were it not for the fact that operating the valves requires an appreciable amount of time. Figure 4 shows graphically the relative amount of time consumed in this operation. As short a cycle as possible consistent with maximum make, is desirable. In selecting a typical cycle, take as an example a 3-minute blast using all the available air. Good practice has shown that for every 1,000 feet of air used, approximately 21½ pounds of steam are required. This ratio of steam and air applies only to low volatile fuels and varies somewhat with different fuels of this class. However, it is to be noted that the steam used per 1,000 cubic feet of gas made in practical operation is nearly double the amount theoretically required.

Therefore if x = the air per minute in cubic feet,

$3x$ = the total air during the 3-minute blast,

$\frac{3x}{1,000} \times (21.5 \text{ pounds})$ = total steam required per run, or

for a 3-minute run $= \frac{(3x) \times (21.5)}{(1,000) \times (3)}$ pounds steam per minute.

If the steam supply is not great enough to give the desired amount of steam per minute, a longer run than 3 minutes will be required for the same 3-minute blow. When a 3-minute blow and a 3-minute run are employed, it may be asked, "Why not use a 2-minute blow and a 2-minute run or a 4-minute blow and a 4-minute run?" The time required to operate the valves is one of the limiting factors in settling this point. The more prolonged the cycle, the smaller is the percentage of time required for changing valves. The average quality of gas made during a prolonged run is not so good, as has already been mentioned. As the cycle is shortened, the percentage of time required for valve operation increases as shown in Figure 4, but a greater portion of the run is made at a higher average generator temperature, resulting in a better quality and greater quantity per minute of blue gas. The shortest cycle that will permit the maximum capacity is desirable. Under average conditions the time of the complete cycle may vary from 4 to 9 minutes when good results are being obtained.

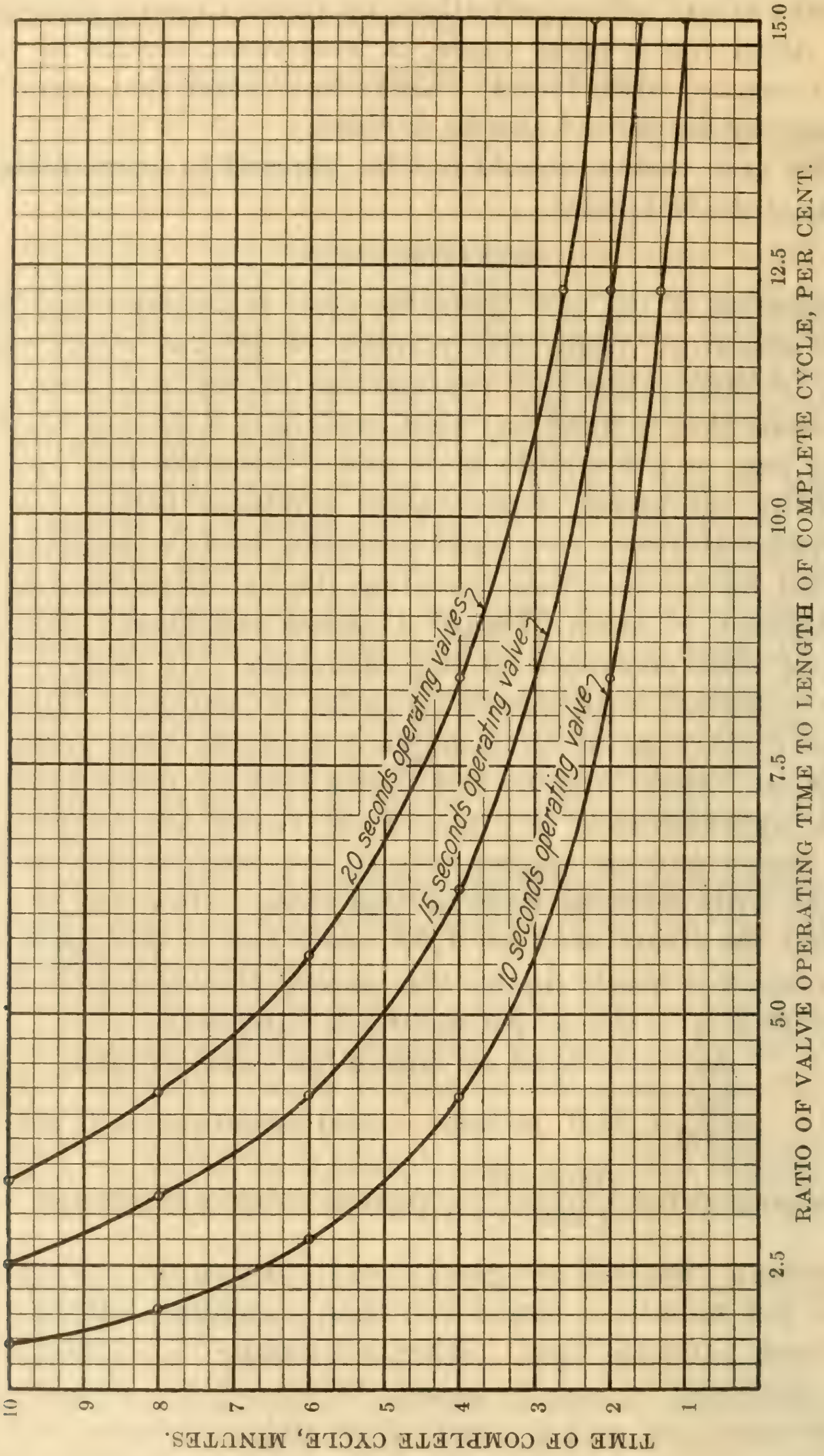

FIGURE 4.—Loss of time due to operation of valves.

UP RUNS AND DOWN RUNS.

In all modern water-gas sets the direction of steam through the fire during the run is reversed at regular intervals. This reversal has been found to be advantageous in many respects. The methods of making up and down runs vary in different plants. In some the steam is reversed during every run, making so-called "split runs." In others, the down runs are made at regular intervals, all other runs being up runs.

Among the advantages realized from these reversals are the following:

1. The clinker can be caused to form near the grates where it can be removed more easily.
2. The upper hot valve is cooled by down runs, preventing overheating during the up run and blow periods.
3. The generator fuel is consumed more completely, less unburned fuel being removed with the ashes and clinker.

When the number of up and down runs is correctly proportioned, the fuel bed is in a better gas-making condition. An excessive number of down runs is to be avoided, since these would result in the top of the fuel bed being unduly cooled, and the grates would have a tendency to become overheated.

CLEANING THE FIRE.

The accumulation of ash and clinker in the generator reduces the make per run, hence efficiency of operation requires that the fire be cleaned at as frequent intervals as will permit a maximum daily make with the least consumption of time for cleaning. How often the generator should be clinkered must be decided by the individual operators and depends upon the fuel used, the total running time, and other factors. If a set is operated 18 hours a day, clinkering is usually done after a 9-hour running period. If 14 hours is the total day's run, the clinkering is done after 7 hours running. When a fuel with a very fusible ash or a high per cent of ash is encountered, it is often an advantage to clinker more frequently. Under some conditions, three cleans a day can be made in the same time required for two, owing to the fact that much more time and care are required for clinkering when the clinker becomes very thick and is high in the generator. A clean fire is essential for a good make and for the generation of blue gas of good quality. The gas maker is usually aware of the condition of his fire even when the figures for the make per hour are not available to him, since the increased resistance of the fire to the passage of air through it causes an increased air pressure under the grates, other conditions remaining the same, as shown by the water gage, and at the same time the air passing through the fire per minute is decreased, as shown by the air meter.

CARBURETION OF GAS.

The time allowed for spraying a definite amount of oil into the carburetor directly affects the time of contact and influences the amount of gas, carbon, and tar formed. If the checkerwork of a 6-foot set occupies 150 cubic feet out of 380 cubic feet total interior volume of the carburetor and superheater, the volume of the remaining free space will be 230 cubic feet. If an average make of 1,000 cubic feet of gas per minute or 16 cubic feet per second at ordinary temperatures is assumed, this will be equivalent to 57.3 cubic feet of gas at 1,400° F. The time of contact will be equal to the volume of free space in the checker chambers divided by the volume of gas passing per second, or $\frac{230}{57.3}=4.0$ seconds. Toward the end of the run the make falls off or decreases considerably. It may be as low as 600 cubic feet of gas per minute, equivalent to 35.8 cubic feet per second at 1,400° F. The time of contact under such circumstances would be $\frac{230}{35.8}=6.4$ seconds. Increasing the quantity of oil added per minute increases the volume of oil gas and consequently the total volume of gas passing through the checkerwork per unit of time, decreases the time of contact of the gas with the checker brick, and increases the concentration of the oil gas formed.

When an excessive amount of oil is used, the time of contact is unduly decreased, resulting in incomplete cracking of the oil and the production of an excessive amount of tar. When this occurs, some undecomposed oil passes through the checker chambers and some appears on the surface of the water in the seal pot. Decreasing the quantity of oil added per unit of time increases the time of contact and is more favorable for the production of carbon or naphthalene. A more consistent product and a better regulation of reactions would be obtained if the production of blue gas were more uniform. However, a desirable feature of this changeable condition is that the time of contact, in ordinary operation, is shortest at the beginning of the run, when the temperature in the checkerwork is the highest. In average practice, the time of contact, figured from the total make over the total run period, is usually 4 to 6 seconds. The most desirable time of contact for any given oil under particular conditions can best be ascertained by actual test.

It is often stated in literature pertaining to water-gas manufacture that 2½ or 3 inches is a "nice" spacing for checker brick. Checkering is often installed without the slightest thought of what the consequences of increasing or diminishing the spacing might be. The general effect of changing the spacing of the checker brick on intimacy and time of contact has been mentioned on page 17. In Figure

5[10] is shown the effect of changed contact time on the make at different temperatures. While these curves would probably be different for the various oils used, the relation of the curves for any particular oil, used for different contact periods would probably be the same.

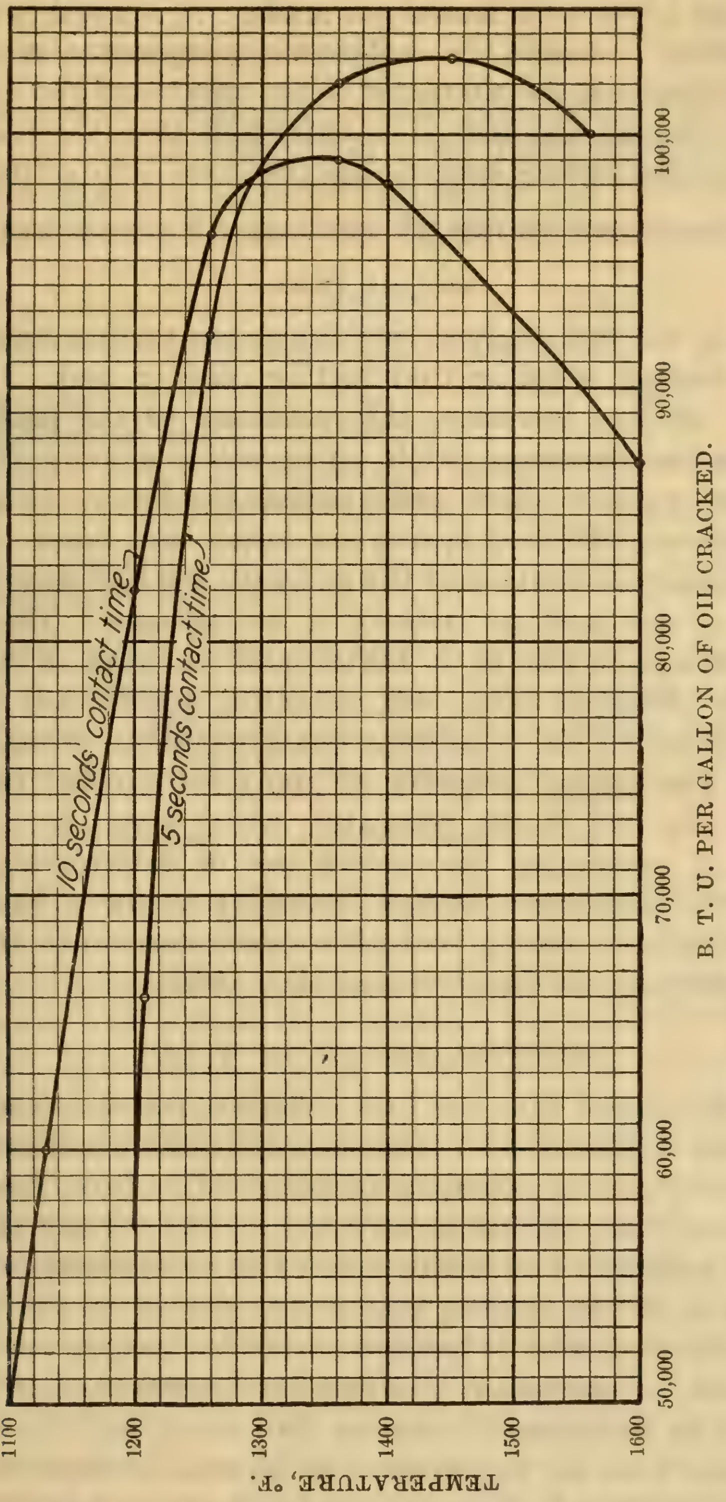

FIGURE 5.—Effect of time of contact and temperature on oil-cracking efficiency.

A consideration of this effect and a study of the results and makes obtained with a particular oil, may show the desirability of a change in the spacing of the checker brick.

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[10] Downing, R. C., Some fundamentals affecting the utilization of gas oil in carbureted water-gas manufacture: Proc. Ill. Gas Asso., March, 1916.

The harmful effects of poor oil distribution in the carburetor have been mentioned in a previous section. In practical operation, the continued use of an inefficient oil spray occasions more frequent cleaning or recheckering of the carburetor and increases the consumption of oil per 1,000 cubic feet of gas made. It is worth while to test the "oil sprays" outside the carburetor, using water or oil, for the purpose of observing the character of the spray and the area that it covers. In making the test, it is important that the pressure and distance from the surface sprayed are the same as in actual use.

CHANGES BROUGHT ABOUT BY THE USE OF BITUMINOUS FUELS.

SIZE OF COAL.

The size of the fuel charged into the generator has direct bearing on gas production, whether that fuel be coke or coal. Usually, as the size of the fuel increases, the resistance to the passage of air through the fuel decreases, while an excessive amount of very fine fuel has the opposite effect and "chokes the fire." As the size of the fuel increases, the void spaces are larger and fewer in number, and the intimacy of contact of the gas with the fuel decreases, *when the volume of air used per minute is not changed.* The fuel constantly decreases in size as it burns, and the rate of combustion varies with different fuels and operating conditions. Attention here is confined to the conditions obtaining when bituminous fuels are used. The coking property of many bituminous fuels causes matting of the fuel in the generator, which tends to increase the difficulties of calculating the correct size or determining one best size for given conditions. It can be said that for a fuel of given size the bituminous coking coal offers more resistance to the passage of air through the fuel bed than does coke.

EXPOSED SURFACE OF FUEL.

It has been stated that the fuel surface exposed to the action of air and steam is greater with coke than with bituminous coal, due to the shape and porous structure of coke. The belief seems to be quite common that the usual decrease in the volume of gas from bituminous generator fuel is due to this fact to a considerable extent. The author is of the opinion that practically all of the blue gas is made from the coal after it has been coked in the generator and that little is made by the action of steam on the uncoked coal. It has been shown by Boudouard[11] that at 650° C. (1,202° F.) it takes 12 hours contact time for equilibrium to be reached between CO_2 and carbon, and at the end of this time only 39 per cent of CO is formed from 100 per cent of CO_2. It is quite evident that practically no blue gas is made at or below this temperature. Furthermore, coal is coked, at least on the surface, at this temperature. Evidently the surface differences between coal and coke do not, of themselves, cause a great difference in the capacity of a given set.

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[11] Boudouard, O., Sur la décomposition de l'acide carbonique en presence de charbon: Compt. rend., t. 128, 1899, pp. 824–825.

CHARACTERISTIC PROPERTIES OF COAL AND COKE.

The properties of bituminous coal are quite different from those of coke, and it is not surprising that these differences require special consideration when the one is substituted for the other as generator fuel. Some of these differences are the following:

	Coal.	Coke.
Volatile matter……per cent	30 to 40	3 to 8
Moisture……do….	6 to 12	[a]5
Ash:		
From Illinois coal……do….	10	16
From eastern coking coal……do….	6	9
B. t. u. per pound……	11,500 to 13,000	12,000 to 13,500
Caking tendency shown when heated in a generator……	Variable.	None.

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[a] Unless freshly quenched or standing in rain.

The per cent of ash given for coke is greater than that for coal. When coke is compared with the coal from which it is made, this relation is correct. However, coke made from eastern coal may have less ash than some Central District bituminous coals.

EFFECT OF COKING PROPERTIES.

The caking or coking property of bituminous coal determines, to some extent, the operation and performance of a generator. It affects, among other things, the quantity of air per minute passing through the fire with a given blast pressure, the size of the fuel charge, the frequency of charging, the size of fuel that can be used, and the temperature in the generator.

When a coking coal is being blasted volatile matter and moisture are expelled from the coal as the temperature is raised, and the outer surface, which is the first to become hot, begins to coke. When this coking takes place there is a natural tendency for the fuel to mat. This mat offers more resistance to the passage of air than does loose fuel, and if means are not found to prevent caking, the resistance to air may become so great as to reduce the air per minute of blast, at a given pressure, as much as 20 per cent. Large fuel charges at long intervals or charges of small fuel accentuate the matting tendency, while with smaller and more frequent charges of large fuel the matting decreases. The matting of the fuel reduces the temperature in the generator, due to the decreased amount of air that can pass through the fuel bed per minute at a given blast pressure.

QUALITY OF BLUE GAS AND BLAST GAS.

When the usual operating methods applied to coke are employed with bituminous coal, the fuel in the upper part of the generator is ordinarily not heated to so high a temperature as when coke fuel is used. This top fuel is being distilled during the run, and the distillation products alter the composition of the gas leaving the generator. The gases produced during the run and the blow with coal as generator fuel are therefore different from the gas produced by coke fuel. Analyses of these gases have been made at various stages of the operation and are given on page 35.

When fuel is blasted in a water-gas generator, combustible gas is produced which is burned by the addition of secondary air in the checker chambers. This gas is produced as a result of two chemical reactions, which have been mentioned previously and are repeated here for clearness. The first reaction to take place is represented by equation 4:

4. $C+O_2=CO_2$.

In this reaction there is complete combustion of the carbon to CO_2, which is not combustible. The heat of combustion of the carbon is, to a great extent, taken up or absorbed by the fuel in the generator. As this fuel becomes hotter, a point is reached where the CO_2 combines further with carbon and produces CO as in equation 3:

3. $CO_2+C=2CO$.

The CO thus generated is the combustible gas that may be burned in the checker chambers. As the fuel in the generator becomes hotter, reaction 3 takes place to a greater extent until practically all of the CO_2 produced is converted into CO before it leaves the generator. Since there is only 20.9 per cent by volume of oxygen in the air, only 20.9 per cent of carbon dioxide could be obtained in reaction 4, while, according to equation 3, 41.8 volumes of CO can be produced from 20.9 volumes of CO_2.

When a fuel containing a high per cent of volatile matter is blasted, the quantity of combustible blast gas produced is increased by the amount of volatile matter driven off during the blow if other conditions remain the same. This volatile matter usually has a greater heating value per cubic foot than CO has; hence the heating value, as well as the volume of the blast gas, is increased. The heating value and volume obtained depend upon a number of variables, including the following:

1. Kind and size of fuel.
2. Volatile content of the fuel.
3. Cycle.

4. Temperature attained in the generator.
5. Rate and volume of generator air blast.

The following average analyses are typical of blast gases sampled at the generator lid with coke and bituminous coal as fuel:

TABLE 5.—*Average composition of blast gas from coke and bituminous coal.*

Fuel.	CO_2.	O_2.	Ill.	CO.	CH_4.	H_2.	N_2.	Total.	B. t. u. per cubic foot.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Coke	10.0	0.4	0.0	21.0	1.2	0.0	67.4	100	90
High volatile bituminous coal	7.8	.0	.3	18.7	3.2	6.7	63.3	100	123

Different fuels when-blasted will give gases of different composition. The above table merely indicates the differences in composition and heating value that may be expected when similar fuels are used.

Similarly, with-high volatile fuel the blue gas produced during the steam run is different in quality and quantity from that when coke is used. The quality is improved by the volatile matter from the coal, the extent of improvement depending on the amount and kind of volatile matter in the fuel, on the variables just mentioned pertaining to blast gases, and on the quality and quantity of steam used during the run. The following average analyses are typical of blue-gas samples taken at the generator lid with bituminous high-volatile coal and coke fuels:

TABLE 6.—*Analyses of blue gas sampled at generator lid.*

Kind of fuel.	CO_2.	O_2.	Ill.	CO.	CH_4.	H_2.	N_2.	Total.	B. t. u. per cubic foot.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Coke	6.7	0	0.0	35.7	0.3	53.0	4.3	100	291.5
High volatile bituminous coal	8.0	0	.5	30.5	3.6	50.0	7.4	100	314

As shown in this table, the quality of blue gas from bituminous coal is higher than that from coke, on account of the increased per cent of hydrocarbons present. This has a marked effect on the amount of oil required for carburetion (see p. 71).

Other conditions remaining the same, the volume of blue gas produced per run or per unit of time is usually less when a coking bituminous coal is used in the generator. There are a number of causes for this decreased output, of which the following are probably the most important:

1. Increased resistance to the air blast offered by the coking coal in the generator on account of the tendency to mat.

2. Decreased volume of air per unit of time, with the same blasting pressure, causing a decreased average temperature of the fuel in the generator.
3. Decreased volume of high-temperature fuel.

In addition to the above a number of other factors doubtless influence the production of blue gas. Among these are the following:

a. Difference in friability of coal and coke.
b. Difference in conductivity of coal and coke.
c. Difference in rate of combustion.
d. Difference in clinker conditions.

The relative importance of these factors varies with different fuels and definite values can not be assigned to any particular factor.

EFFECT ON CARBURETOR AND SUPERHEATER.

HEAT BALANCE.

Since the blast gas is richer when high-volatile fuel is used, a shorter blast is required to produce a definite amount of heat in the checker chambers by the combustion of the blast gas. This means, in the final analysis, either that the checker chambers become too hot during the course of the day's operating, or that the generator becomes too cold. The heat balance is disturbed, and it is apparent that a different cycle or a different method of operation must be employed to obtain the best results with this fuel.

DEPOSITS IN CHECKER CHAMBERS.

Occasionally powdery or granular deposits of carbon have been observed in the checker chambers, more particularly in the superheater. The quantity of carbon deposited, whether it is a powder or the solid deposit often found in the carburetor, depends on a number of variables, including the kind of oil used, the time in which oil is admitted, the spacing of the checker brick, the temperature in the checker chambers, the temperature in the generator, the kind of generator fuel, and the method of admitting secondary air to the carburetor.

EFFECT ON OIL CRACKING.

The variable conditions affecting the cracking of oil have been discussed in a previous section (see p. 16). The use of coal as generator fuel changes many of these conditions, with a consequent effect on the efficiency of oil cracking. The chief changes brought about are in the quantity and quality of the blue gas and the temperature in the cracking chambers.

SMOKE PRODUCTION.

The production of smoke is a characteristic feature of bituminous coal as fuel. Since the surface fuel in the generator is relatively cool, the fuel emits a tarry vapor when blasted. If the average temperature of the generator fuel is particularly low, the gases first generated on blasting are chiefly CO_2 and N_2. Since this mixture is incombustible it is difficult to burn the tarry vapors produced with these gases. The temperature of the fuel in the generator, then, has considerable to do with the production and possibility of elimination of smoke.

ASH AND CLINKER FORMATION.

With the lower generator temperature that ordinarily prevails when bituminous fuel is used, there is less tendency for clinker to form and a greater tendency for ashes to accumulate. These ashes may occupy a greater volume, weight for weight, than the clinker, and are detrimental to the quantity production of good water gas. However, coal will produce a very hard clinker under some conditions, and the fusibility of the ash of the various coals differs greatly.

EFFECT ON PURIFICATION.

If the gas is thoroughly cleaned before it reaches the purifying boxes, there is no reason to believe that the efficiency of the purifying process will be affected in any way by the use of coal fuel unless it contains an excessive amount of sulphur. On account of the larger amount of tar produced with coal the gas is not thoroughly cleaned in some plants, and the purifying material has been known to be ruined by lack of care in this respect.

USUAL METHODS OF OPERATING WITH BITUMINOUS COAL FUEL.

HEAT BALANCE AND CYCLE.

With the changed composition of the blast and blue gases, it is natural to suppose that the heat balance throughout the set would be disturbed by the changes brought about in substituting coal for coke in the generator, and such is actually the case. In the usual operation with coal fuel, the checkering tends to become too hot, frequently rising as high as 1,600° F., while the generator fuel is not hot enough. This is due principally to the greater heating value of the blast gas, which in turn can be explained by the presence of considerable volatile matter from the coal. The greatest obstacle to the substitution of coal for coke as generator fuel is the maintenance of high temperatures properly proportioned throughout the different parts of the set. Since 75 to 80 per cent of the total gas made is produced in the generator, the importance of maintaining the correct temperature there is evident.

In the usual operation of a set, with bituminous coals as generator fuel, the tendency for unequal distribution of heat in the set must be checked by one of the three following methods: (1) Burning some of the blast gas outside the set at the stack; (2) neutralizing some of the excess heat produced in checker chambers, by admitting steam or excess air into the carburetor during the blast; or (3) using an excess of steam during the run without prolonging the blasting time.

Method 1 provides a means for maintaining the desired temperatures throughout the water-gas set, but does so wastefully, since the heat evolved by burning the gas outside the set is seldom utilized. With this method, the loss due to the heat wasted at the stack may be expected to increase as the per cent of volatile matter in the coal increases.

Method 2 is not commonly practiced but offers a possible means of accomplishing the same results as method 1, with similar inefficiency. However, when sufficient air pressure is available to use an excess of air to control the temperatures in the checker chambers, one possible advantage is gained. The carbon deposited in these chambers may be thus burned out or the accumulation of carbon prevented. The cause of excessive deposits of carbon has been mentioned on page 22. See also page 72.

Method 3, which is commonly employed in Illinois, frequently in combination with method 1, results in a high fuel and steam consumption and a considerably decreased output per unit of time. Such an excess of steam consumption during the steam run decreases the fuel temperature unduly and this in turn means that, with the same blast conditions, the blast gas produced will contain more CO_2 and less combustible gases. Thus, on blasting, the complete combustion reaction, $C+O_2=CO_2$, takes place, but the reaction, $CO_2+C=2CO$, discussed on page 8, does not take place to an appreciable extent until later in the blast, when the temperature in the fuel bed is sufficiently high. Method 3 is probably more efficient than operating with normal steam and reduced blasting time, although the desired results have not been obtained from it.

Figure 6 shows the effect on the composition of the blast gases of an excess of steam during the steam run or, what amounts to practically the same thing, a deficiency in the quantity of blast. The first curve shows the change in per cent of CO_2 as the blast progresses, when 40 pounds of steam per minute is used on each steam run. The third curve shows similarly the relative amount of CO_2 in the blast gas at different stages of the blast, operating with the same cycle and using approximately the same amount of air as in the operation represented by the first curve, but with less steam during the run. The per cent of CO present in the blast gas under both of these conditions is shown by the second and fourth curves. The slope of these curves will vary according to the height of the fuel, the condition of the fire, the kind of fuel, the amount of green fuel present, and the way the carburetor is blasted. When opened too wide, the carburetor blast may rob the generator of needed air blast; then the CO_2 curve would not drop so rapidly. These curves are sufficiently representative to show that an excess of steam during the run cools the generator to such a degree that a smaller amount of combustible gas and more CO_2 are produced during the blast.

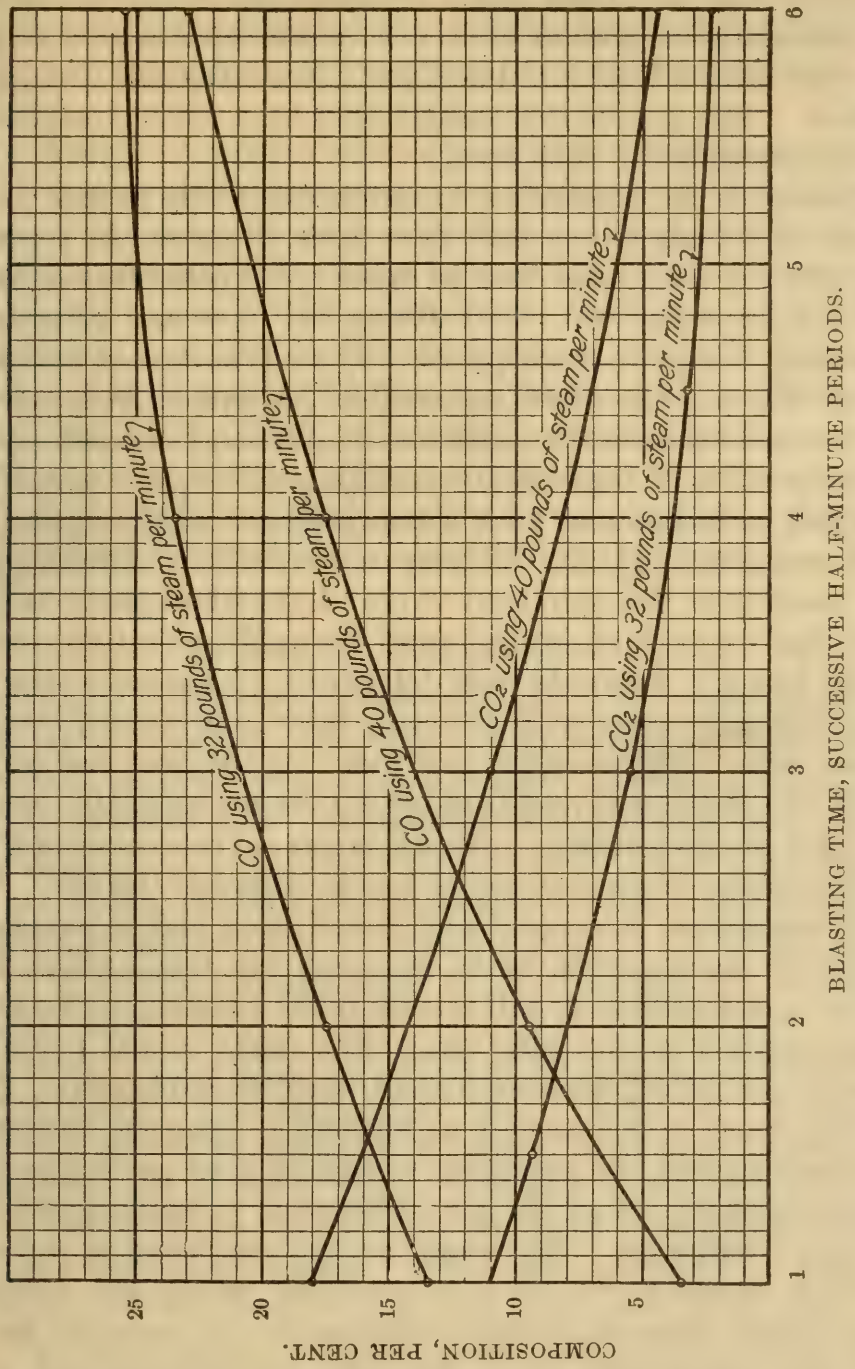

FIGURE 6.—Effect of change in quantity of steam on composition of blast gases. Cycle—3-minute blast and 4-minute run.

It is apparent that by operating according to method 3 a cycle can be found that will result in checker chambers being heated to the desired temperatures only. A combination of methods 3 and 1, wherein some of the blast gas is burned at the stack, permits the same results to be accomplished with a higher temperature in the fuel bed of the generator.

This change in operation may require a change in the operating cycle. Although it is possible to increase the quantity of steam per run in many plants by merely opening the steam valve wider, it may be found necessary to increase the length of the steam run in some plants if the steam supply is insufficient. For example, a plant employing a 3-minute blast and a 3-minute run with coke fuel may find it necessary to operate with a 2-minute blast and a 3-minute run, or even with a 3-minute blast and a 4-minute run when changing to coal. This can be determined only by a consideration of the conditions prevailing in each case.

The factors to be considered in determining the proper cycle of operation with high-carbon fuel have been discussed in a previous section, when it was stated that to make 1,000 cubic feet of finished gas about 1,500 cubic feet of air during the blow and 32 pounds of steam during the run were required. The advantage of making the blow and the run as short as possible consistent with adequate time of contact between the gases and the fuel and without using too large a proportion of the time for changing valves, was pointed out. In changing to bituminous fuel, a readjustment of the cycle is necessary in order to maintain the temperature balance throughout the set, on account of the increased value of the blast gas. Let it be assumed that for a given set the most favorable operating condition with coke fuel is a 4-minute blow followed by a 4-minute steam run, and that the same cycle with the same blast and steam pressures is continued with a high-volatile coal fuel. If the coal has a coking tendency, one of the first results noted will be a matting of the fuel in the top part of the generator, causing increased resistance in the fuel bed and resulting in the passage of less air through the fire. Under these circumstances, the coal is not heated to so high a temperature at the end of the 4-minute blow, although the temperature in the carburetor and superheater will remain fairly constant on account of the richer quality of the blast gas. The make of gas per unit of time during the run will decrease by perhaps 20 to 30 per cent. Should the blast pressure be increased in an attempt to raise the temperature of the generator fuel, the increased volume of blast gas will overheat the checker chambers if all the gas is burned in them, thus disturbing oil-cracking conditions. The usual method employed is a compromise. It is desirable to reach a condition where the volume of generator blast gases is reduced sufficiently to prevent the carburetor and superheater from becoming overheated, and at the same time to prevent undue lowering of the average temperature in the generator fuel. To do this, it is customary to increase the quantity of steam used per minute during the run, or when this can not be done, to lengthen the steam run. At the same time, the blasting period and the air pressure are unchanged. The result is that the generator fuel does not have so high a temperature at the end of the run. On blasting, the fuel will not now generate so much CO, since complete combustion takes place to a greater extent in the generator with the formation of CO_2. More heat is being stored in the generator per minute of blast in this case, a fact that is readily understood when the heat reactions of carbon and oxygen are considered.

One pound of carbon burning to CO_2 liberates 14,544 B.t.u., while 1 pound of carbon burning to CO liberates only 4,350 B.t.u. However, the same average temperature of generator fuel is not reached at the end of the blow because the initial temperature was considerably lower. This results in the production of less blue gas during the steam run, containing a higher per cent of CO_2. Since with this method less CO for heating the checker chambers is formed during the blast, these chambers are not usually overheated. Should the temperature still be a little high, and it is not desirable to reduce it by cooling the generator further with a greater excess of steam, it may be lowered by overblasting the carburetor (using an excess of secondary air).

DETERMINATION OF OPERATING CYCLE.

Conditions in different plants will affect the selection of a favorable cycle for coal fuel. A method of operating has been devised by the authors making use of the so-termed "blow run," which involves other considerations in determining the operating cycle and which is discussed later in this bulletin on page 62. The following suggestions are, however, offered for guidance in determining the cycle to be employed when operating a water-gas set with the usual methods.

1. It is usually advantageous to use as much air as possible per minute of blow.
2. When a run and a blow of about equal length are used, enough steam should be used during the run, in order that no appreciable amount of generator blast gas in excess of what is required to heat the checkerwork properly will be produced during the blow.
3. When sufficient steam is not available to accomplish this, with the steam run the same length as the blow, the duration of the steam run should be increased until the desired result is obtained.
4. The use of steam in excess of what is required to accomplish the above should be avoided.
5. The CO_2 content in the blue gas should be reduced as much as possible, consistent with burning all of the generator blast gas in the checker chambers.

COAL FUEL IN THE GENERATOR.

ARCHING AND CAKING.

Coke in the generator presents a porous loose mass to the passage of air and gases through the fire, while on the other hand most freshly charged bituminous coals tend to cake and run together. This caking, if excessive, is evidenced by increased blast pressure under the grate, other conditions remaining the same; and, if the set is equipped with an air meter in the generator blast line, a decided decrease in the amount of air going through the fire will be indicated soon after a fresh coaling is made. This is especially true when excessively heavy charges are made. It is frequently customary in plants operating with coke to make one or more fuel charges two or three times the size of the normal running charge at the beginning of the day's run. With ordinary bituminous coal this procedure would almost certainly choke the generator. In general, it may be said that large egg-size coal, even with the caking controlled, offers more resistance to the passage of air than does coke, and the addition of a large charge of green coal causes an excessive increase in this resistance. When the fuel cakes, it forms a nearly impenetrable arch over the fire, which hinders the passage of air, slows up the combustion during the blast period, decreases the temperature of the fuel bed, and results in a great decrease in the amount of gas produced during the run. This arched mass of fuel frequently remains in place where formed, even after the already coked fuel beneath it has burned away, leaving a hollow space between. The arch may be so firmly established that it is necessary to break it up with bars before another coal charge can be added. This, of course, is additional labor, even if it were not an indication of an inefficient operating condition. Methods of overcoming these difficulties are discussed later under the Streator experiments (see p. 47).

It was formerly believed by some operators that when bituminous coal was used as generator fuel, practically all of the volatile matter would be driven off from a fresh charge during the first blast after coaling. On the contrary, it is found that the surface of the fuel bed remains fairly cool from charge to charge. The surface of a charge has not been entirely converted into coke when the next charge is added. The rate of conversion into coke will of course depend upon the temperature in the generator, which in turn is dependent upon the amount of air passed through the fire during the blast period and the amount of steam used during the run. On one occasion, a 6-inch lump of coal removed from the fire just before a fresh charge was made showed about three-fourths inch of coke on those faces perpendicular to the laminations of the coal, while the other two faces had coked to a depth of about one-fourth inch.

The fact that the surface of the fuel usually remains relatively cool may delay the ignition of the generator gases when the lid is opened for charging. These gases are usually combustible and a continuously burning pilot light or some form of torch kept ready to ignite them will avoid any unnecessary delay caused by their failure to ignite when the lid is opened. As with coke fuel, care should be taken that the gases are ignited before attempting to charge.

CONTROL OF CLINKER.

The difficulty experienced from clinker in plants using bituminous coal varies with the kind of coal and with the operating conditions employed. In plants where comparatively low generator temperatures are carried, the fusing point of the ash may not always be reached, with the result that no clinker is formed but instead a bed of loose ashes. In other plants where more air blast is used in the effort to maintain a higher fuel temperature, a very hard clinker may be formed.

In general, the ash of Central District coals fuses at a lower temperature than that from some of the better eastern cokes; therefore special attention must usually be given to operating methods when these coals are used.

Owing to the greater friability of some of these coals, considerable fine material is almost inevitably introduced into the generator when charging. If no fuel spreader is used or the one in use is inefficient, most of the fine coal is deposited in the center of the fuel bed, increasing the thickness and resistance to draft of that part of the fire. This, with the coking tendency of the fuel, causes most of the air blast to pass up around the generator wall, giving a more intense combustion there than in the middle of the fire and resulting in a fusion of the ash and the formation of clinker or "edgings" on the wall. If this clinker is high up on the wall, barring down from above may be necessary, and in any case the deterioration of the lining bricks is hastened.

The difficulty can be largely overcome by the use of an efficient spreader which will deflect most of the coal to the outer edge of the fuel bed and by split runs or a greater percentage of down runs, which will usually result in keeping the clinker formation nearer the grate, where it can be more easily handled. Figure 7 illustrates a type of fuel spreader that is very efficient when properly designed for the generator with which it is to be used. By cleaning the fire at specified intervals the accumulation of clinker can be regulated to such a thickness that it can be readily removed.

PREVENTION OF STICKING OF VALVES BY TAR DEPOSITS.

The gases leaving the generator when bituminous coal is used consist not only of carbon monoxide, hydrogen, and carbon dioxide, the usual constituents of water gas, but of varying amounts of hydrocarbons. Some of these are permanent gases, but tarry vapors are also present that are partly distilled in their passage through the set and if condensed deposit as a sticky viscous pitch. This pitch is in evidence at any part of the machine where there is a slight leak, as, for example, at the hot valve and the carburetor and superheater blast valves, around the oil-spray stuffing box, and occasionally at the generator lid. The pitch is fairly fluid when hot, but when cool is tough and viscous and is likely to cause valves to stick very tightly.

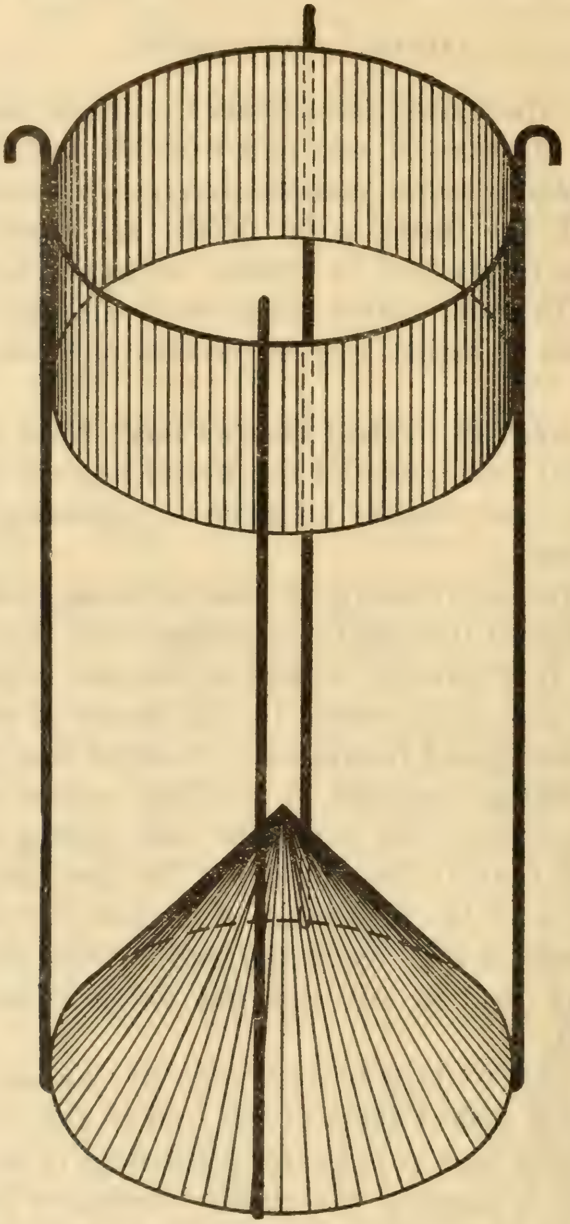

FIGURE 7.—Fuel spreader.

This need give little trouble if preventive measures are taken. Usually a fairly fluid mixture of lubricating oil and flake graphite, smeared occasionally on the valve stems, will prevent the sticking. In general, troubles of this sort are reduced to a minimum when proper temperatures are maintained throughout the set and the weight of charges is not excessive. In plants operating with but short lay-overs no trouble is experienced.

REDUCED CAPACITY WITH COAL FUEL, WITH THE USUAL OPERATING METHODS.

The chief difficulty encountered by gas companies, especially the large ones, when they use bituminous coal instead of coke for generator fuel is decreased capacity. Various operators have reported a decrease of 25 or 30 per cent in the possible output of the plant when coal is substituted for coke. One reason for this decrease seems to be the difference in resistance of the two fuels to the passage of air under the same blast conditions. The rate of combustion of the fuel, and therefore the rate at which the fuel acquires a gas-making temperature, seems to be roughly proportional to the amount of air passing through the fire in a given time. If the volume of air passing is augmented by increasing the air pressure, the combustion is more rapid, and the fuel bed is brought more quickly to the proper temperature for decomposing steam. In a majority of gas plants the blowing capacity is limited, and the initial pressure at the base of the generator is conditioned by the type of blower used. Consequently, since the coal fuel bed offers more resistance to the passage of air through the fire than does coke, more air is transmitted at the pressure available with a coke fire than with coal, the combustion is more rapid, and during the run the gas production is greater with coke. If it were possible to force the same volume of air through the coal fire in a given time, it seems likely that the volume of gas produced during a given time would more nearly approach that with coke.

Under usual operating conditions, therefore, a blow period takes longer in proportion to the length of steam run to bring the fuel up to the same working temperature with coal than with coke. On account of the greater amount of volatile matter in the coal, the amount of combustible gas given off during the relatively longer blow period is more than sufficient to maintain the requisite temperatures in the carburetor and superheater; consequently a blast of such length as will heat the generator suitably overheats the other chambers (if the gas is entirely burned in them) or necessitates the burning of considerable gas at the stack. Either condition is undesirable and wasteful. It may be found impossible to burn this excessive production of combustible generator blast gases in the set even with the carburetor blast valve wide open, unless the volume of these gases is decreased by partly closing the generator blast valve, or the fuel bed is unduly cooled by excessive use of steam during the steam run. In either case, however, the generator will not attain the desired temperature so quickly. In some plants where there is an excess blowing capacity it may be advisable to cool the carburetor and superheater by overblowing them rather than by underblowing or oversteaming the generator. With any of these methods, however, capacity can only be obtained by sacrificing a considerable amount of combustible gas with a resultant waste of fuel.

FUEL AND OIL ECONOMIES.

Potential fuel and oil economies will vary in different plants, not only with the operating conditions employed, but also with the composition and quality of the coal and oil used, the daily operating time, and the prevailing weather conditions; hence, operating results can only be compared when operating conditions are known. Table 7 is a summary of results obtained with various fuels and oils in a few plants. The operating conditions are given when known. The data given for plant E in this table were obtained by the authors at Streator, Ill., with coal fuel, by methods similar to those employed in the other plants. These results agree fairly well with others reported, although small differences are due to seasonal variations, the Streator data being obtained in the late fall, the remainder in summer. It will be noted that the oil used is from one-fifth to one-half gallon less per 1,000 cubic feet of gas when made with coal fuel than when made with coke. The generator fuel is increased about 30 per cent when coal is used, and the per cent of ash and moisture in the coal is not excessive. However, the lower cost per ton of coal as compared with coke usually much more than offsets the difference in fuel consumption per 1,000 cubic feet of gas.

TABLE 7.—*Practice at five water-gas plants.*

Details of practice.	Equipment.					
	2 6-ft. United Gas Improvement Co. sets. Generator, 4 ft. internal diameter.		1 8-ft. Western Gas Construction Co. set. Generator, 6 ft. internal diameter.[a]	2 8 ft. 6 in. United Gas Improvement Co. set. Generator, 6 ft. 6 in. internal diameter.[a]	1 8 ft. 6 in. Gas Machinery Co. set. Generator, 6 ft. 6 in. internal diameter.[a]	1 6-ft. United Gas Improvement Co. set. Generator, 4 ft. internal diameter.[a]
	Plant A.		Plant B.	Plant C.	Plant D.	Plant E.
Kind of fuel	Indianapolis egg-size oven coke.	Franklin County, Ill., lump coal.	No. 4 seam Indiana lump coal.	Franklin County, Ill., egg coal.	Jackson County, Ill., lump coal.	Williamson County, Ill., large egg coal.
Generator fuel per charge....lb.	500	750	1,000–1,100	1,100	1,600–1,800	659.
Frequency of charging generator	30 min	35 min	Every 5 runs	Every 5 or 6 runs.	Every 8 or 9 runs.	Every 5 runs.
Air per minute....cu. ft.	1,800	1,027	3,200 (?)	No meter	No record	1,200.
Steam per minute: Up run....lbs.	22	28	55	40	60	34.
Down run.do.	27	33			45	32.
Running time....hr. per day.	14.6	18.3	14.4	22	18–20	7.33.
Cycle: Blow.....min.	3	3	2	3	2	3.
Steam run....min.	5	5	3	4	3	4.
Split runs....do.	2 up, 2 down. 1 up.	2 up, 2 down. 1 up.	½ min. up, 2½ min. down.	No split runs	No split runs	2 up runs to 1 down run.
Kind of gas-oil used.	32 to 36° B.	32 to 36° B.		28 to 30° B.	28 to 30° B.	28 to 30° B. Texas.
Gas made per run....cu. ft.	3,633	2,900	3,800	4,550	4,400	2,831.
Gas made per hour....cu. ft.	27,245	21,750	41,800	38,700	52,800	23,468.
Generator fuel per 1,000 cu. ft. of gas....lbs.	32.75	44.5	42.5	40	42	46.
Oil per 1,000 cu. ft. gas....gal.	3.54	3.13	2.68	3.2	3	2.97.
Heating value of gas....B. t. u.	600	600	575	565	588	578.
Temperature bottom superheater....°F.	1,300 to 1,400.	1,300 to 1,400.	1,240 to 1,280.	1,300	1,300 to 1,400.	1,280.
Cleaning time	2 hrs. per day.	2 hrs. per day.	1 hr. for 2 cleans.	2 hrs. per day.	2 to 2½ hrs. per day.	½ hr. per day.
Gas per min. per sq. ft. of grate area....cu. ft.	58	46	45	40	44.4	56.5.
Steam per 1,000 cu. ft. gas....lbs.	33.7	52.6	43	30.2	36	42.3.
Air per 1,000 cu. ft. gas....cu. ft.	1,480	1,060	1,680 (?)	No meter		1,272.
Blast pressure....in. of water.	18 to 20		16	16 to 18	20 to 22	17 to 18.

[a] Data on practice with coke fuel not available for publication.

SELECTION OF STREATOR PLANT FOR EXPERIMENTS.

Since water-gas operation involves so many variable conditions, it was decided that satisfactory experiments with bituminous coal could be conducted only on a commercial scale. With the realization that some experiments might decrease production capacity considerably before an efficient operating method was evolved, it was deemed inadvisable to select for experimental work a plant that was working at capacity, since operation for a few hours under a trial set of conditions might jeopardize the gas supply to the community being served without proving conclusively the source of the difficulties.

The Public Service Co. of Northern Illinois offered the facilities of its Streator plant for tests; this offer was accepted because the plant is well equipped and has a generating capacity several times as great as any demand likely to be placed upon it. Moreover, it is relatively small, and experiments with various coals, some of which might prove to be entirely unsuitable for water-gas manufacture, would not involve the purchase of so much worthless material as would be required at a larger plant.

EQUIPMENT OF PLANT.

The generating equipment of the Streator plant consists of two 6-foot water-gas sets, one of United Gas Improvement Co. construction, the other built by the Western Gas Construction Co. These sets are used alternately, one being operated while the other is down for recheckering or repairs. The sets stand side by side in the same generator house, and the steam and blast supply lines to the sets, as well as the collecting mains from them, are interconnected. The blast is supplied by one of two No. 5 turbine-driven blowers connected by elbows into the ends of a sheet-iron T. The side outlet from this T passes through a brick wall to the generator house where the branches of a Y connection carry the blast to the two sets. A sheet-iron gate in the branch to the Western Gas Construction Co. set makes possible the shutting off of this branch when the other set is in use. There is no such provision, however, in the other branch.

Each set has the usual pressure gages, wash box, and scrubber, and one water-cooled primary condenser is used in common by both sets. In addition, the United Gas Improvement Co. set is equipped with steam and air flow meters. There is also an indicating pyrometer which can be used with either set, consisting of an indicator and two fire ends, one inserted near the middle of the carburetor and the other near the the top of the superheater. No means are available for recirculating wash water from the tar separators. Hot water from the condenser is used in the Western Gas set when it is in operation, but, owing to a difference in the elevation of the wash boxes and the lack of a suitable pump, cold fresh water only can be used in the other set. The gas, after leaving the primary condenser, passes to two relief holders, one of 30,000 cubic feet, the other of 25,000 cubic feet capacity. These holders are usually employed together to diminish the back pressure on the set. The outlets of these holders lead to an exhauster. A by-pass also permits connection of the exhauster with the inlet of the relief holders. On account of the small size of the holder connections, this by-pass is used but a part of the time, restricting the fullest utilization of the holders as condensers. The gas from the exhauster passes through a water-cooled secondary condensor, thence to an outdoor rectangular shavings scrubber, from which it passes through two cylindrical outdoor purifiers connected in series by a center seal. These purifiers are so arranged that the gas can enter at the middle and leave by the top and bottom, or vice versa. After the purified gas is measured by a 6-foot station meter, it passes into a 100,000 cubic foot storage holder, then through a station governor to the city. The gas is tested at the gas office, about 1 mile east of the plant.

The normal daily output of the plant during the experiments was about 165,000 cubic feet. Since the capacity of either set was several times greater than the daily output, it was seldom necessary to operate more than 6 or 7 hours a day, and local conditions made even this short operation intermittent. Therefore, while the experiments served to point out operating methods and to solve some of the problems arising from the use of coal fuel, as well as to indicate the relative value of various available coals, they could not show conclusively what fuel and oil efficiencies and production capacities might be realized from continuous operation in larger plants. Gas engineers generally admit that better fuel efficiencies can be obtained with continuous than with intermittent operation. Since a considerable portion of the operating day elapsed before the carburetor and superheater of the set were in condition to fix the oil properly, it would seem that better oil efficiencies could be realized at a plant operating full time. The application of the Streator methods to conditions in other plants will be discussed in a later section of this report. The Streator experiments point the way to additional investigations and suggest solutions to some troublesome problems.

PREPARATION FOR TESTING BY CHECKING APPARATUS.

Before the experiments were begun, the apparatus to be used in determining the operating conditions was tested and calibrated in so far as facilities permitted. The gages of the steam meters were calibrated by checking the reference points of each against a standard pressure gage. The zero point was determined when the hands were so set as to show correct readings in the working part of the scale. The pyrometers were checked by comparison with a calibrated pyrometer. The fuel was forked from the storage pile into tared wheelbarrows and weighed on platform scales. The oil used was measured by a standard oil meter, which was calibrated against oil-tank measurements over a period of several weeks. It was found that on account of variations in temperature and the difficulty of taking sufficiently accurate measurements, the daily oil consumption could not be determined accurately from daily tank measurements. Meter registrations with the factor determined were therefore used. When gas measurements were being made, it was assumed that the station meter, which had been overhauled and tested within the past two or three years, was substantially correct. Care was taken that the water was kept at the proper operating level.

GAS-ANALYSIS APPARATUS AND METHODS.

Throughout the experiments, frequent analyses of blast, blue, and finished gases were made to guide experimental procedure and to determine the effect of various changes in operation. The gas-analysis apparatus was of a modified Orsat type, consisting of a water-jacketed burette with a three-way cock connected to a glass manifold, from which branches led to the various pipettes through glass stopcocks. Carbon dioxide, oxygen, illuminants, and carbon monoxide were absorbed in solutions of potassium hydroxide, potassium pyrogallate, bromine, and acid cuprous chloride, respectively. Two pipettes were used for the absorption of carbon monoxide, one being so arranged that the gas could be bubbled through the solution. The other absorption pipettes contained glass tubes to give more absorption surface. Absorption was facilitated by passing the gas back and forth from the burette to the pipette several times until the volume ceased to contract. The copper chloride solutions, frequently renewed, were kept in the cuprous condition by pieces of copper gauze. The methane and hydrogen in the gases analyzed were determined by combustion of the residual gas from the absorptions with pure oxygen in a special pipette over gas-saturated water. The usual procedure was to pass a measured volume of oxygen into the pipette, then to pass a measured volume of gas into the pipette very slowly over a spiral of platinum wire heated by an electric current. Usually the entire gas sample remaining after the absorptions was burned. The current was then interrupted and the burned gas allowed to cool and to return to the burette for measurement. The methane and hydrogen were computed in the usual manner from the contraction and subsequent absorption in potash. Even the leanest blast gases could be analyzed without difficulty by this method.

Hydrogen sulphide in the unpurified gas was determined at frequent intervals by the Tutweiler apparatus, using an iodine solution so made that 1 cubic centimeter was equivalent to 100 grains of H_2S per cubic foot of gas. Daily stain tests were made with lead-acetate paper at the office where the heating value was taken. Total sulphur determinations were made with a Drehschmidt total-sulphur apparatus, in which the products of combustion from a metered volume of gas were bubbled through a solution of sodium carbonate to which a few drops of bromine had been added. The solution was divided between two wash bottles of a type that gives very intimate contact of gas with solutions. The gas was burned at the rate of about one-half cubic foot per hour. After about 2 cubic feet of gas (corrected) had been burned, the solution was washed from the apparatus into a beaker, acidulated with hydrochloric acid, and boiled to expel carbon dioxide. The sulphur was precipitated by barium chloride in the usual way and the precipitate of barium sulphate was removed on an ashless filter, ignited, weighed, and the amount of sulphur calculated in grains per 100 cubic feet (corrected) of gas burned.

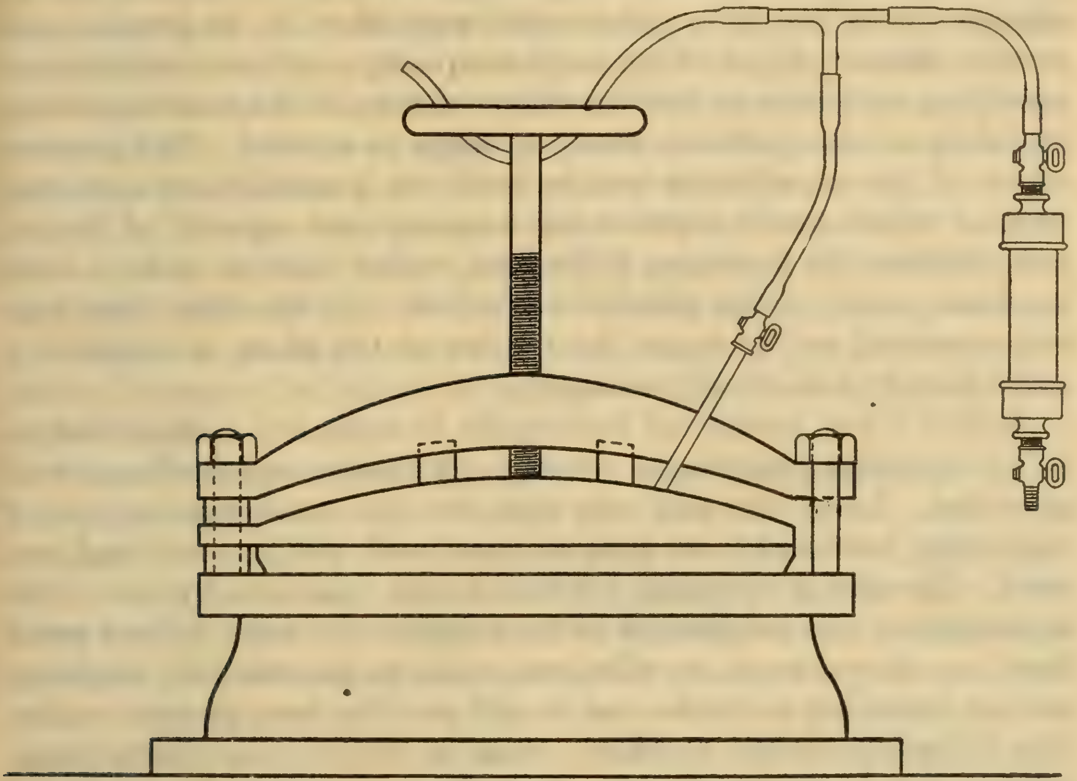

FIGURE 8.—Apparatus for sampling gas at generator lid.

SAMPLING.

Samples of gas were collected for analysis in sampling tubes made from 12-inch sections of 2-inch pipe fitted at each end with reducing couplings and ordinary gas hose cocks. Before a sample was taken, the sampling tube was filled with water which had been previously saturated with the gas to be analyzed. In taking samples at the stack or generator lid over a very short time, as, for example, during a fraction of a minute, the arrangement shown in Figure 8 was employed. Since the gas was under pressure, a continuous purging of the connecting tube through the tee and the side outlet connection was assured, and the uniformity of the sample collected was obtained by making the outflow of water from the sampling tube as uniform as possible. By having several such tubes ready it was possible to collect more than one sample during a single run or blow, and from the analyses to plot curves showing the changing composition of the gases.

The coal was sampled by laying aside at regular intervals a forkful of the coal that was being loaded into the charging buggy. This composite sample of forked coal was prepared for analysis by crushing and quartering it repeatedly according to the standard Bureau of Mines method.

EXPERIMENTAL PROCEDURE.

In beginning the Streator experiments the plan adopted was to operate the plant in a commercial way; that is, to produce the needed amount of gas of the requisite quality, and yet to manipulate operating conditions so that the effects of some of the more important variables on the problems involved might be studied. The primary object of the experiments was to work out a satisfactory operating method which would improve the economy and capacity of the set and decrease the operating difficulties, rather than to make a more academic study of the principles involved. At the same time care was exercised not to upset the routine of the plant operators any more than was absolutely necessary.

At first it was considered inadvisable to make any radical changes in the operating conditions. Accordingly the experiments began with coke fuel. Later coal and coke mixtures were used, the per cent of coal being increased from time to time until 100 per cent coal was used. Changes in operating conditions were made one by one. The investigation was not limited to the solution of certain defined problems; on the contrary, an effort was made to ascertain the combination of operating methods that would give the best general results. The following specific problems, most of which were closely interrelated, will be discussed: Obtaining the cooperation of gas makers; the use of coal and coke mixtures; selection of coal; control of the arching and caking of coal in the generator; reduction of capacity with coal fuel, employing the usual operating methods; the air purge; smoke prevention; and control of clinker.

The solution of these problems, with the exception of the first, which is psychological, necessitates the study of the effects of the several variables. Only those that seemed to exert the greatest effect and that could be studied without greatly disturbing the routine of operation or the service being rendered by the gas company to the community were studied with a view to determining their influence. Among the more important phases of operation studied were: Coal and coke mixtures, depth of the fuel bed, weight and frequency of charges, rate of blasting and length of blasting period, rate of steaming and length of steaming time, proportioning of up and down runs, and behavior of various coals.

The procedure followed was not exactly in the order here outlined. For example, in the study of various mixtures of fuel several days were spent on a mixture of certain proportions, and the effects of various blasting and steaming conditions, the weight of the charges, and other conditions were studied for the mixture.

The same procedure was repeated with various mixtures. The variables studied with a given mixture were those that seemed to be of the greatest importance in a given case. The procedure from day to day was governed by the results obtained with a given set of conditions, the analyses of gases produced in various stages of the operation, and other observations. After experimental determination of the conditions that seemed to give the best results with a given mixture of fuels, a run of several days was usually made with the conditions held as constant as possible to ascertain whether the results were maintained or were disturbed by other factors not under control. Throughout the experiments it was necessary to contend with certain deficiencies in plant equipment and with incidents in operation which introduced changes; therefore the only way to draw conclusions is to consider several days' results in perspective and to make allowances for known occurrences which affected the results on certain days.

Although the actual operating results largely determined the operating procedure from day to day, gas analyses gave considerable assistance in studying the effects of changes in conditions. Arrangements were so made that samples of gas could be collected at the generator lid, from the down-run connection between the base of the generator and the carburetor, and at the stack. Frequent analyses were made of gases collected at these points. It was possible to observe the variation in composition of the generator blast gas or the blue gas from minute to minute during a given blow or run, or to compare the average composition of the gases of successive blows or runs. In this way, the effects of changing temperature in the fuel bed during a given part of the cycle or the effect of changes in depth of fuel over several runs could be studied. Moreover, the completeness of combustion of blast gases in the set and the amount of excess secondary air could be ascertained from analyses of gas samples taken at the stack. Analyses of the finished gas gave additional information relative to blue-gas and oil-gas production and suggested changes in operating conditions.

COOPERATION OF GAS MAKERS.

Securing the cooperation of the gas makers presented little difficulty in the Streator work, since the plant had been operating with coal for several weeks prior to the tests and the force had some familiarity with operating conditions for this fuel. In some plants, however, the opposition of the working force has been one of the chief difficulties encountered.

The uncertainty of the results to be obtained with an unfamiliar fuel and the lack of a money incentive for testing new and untried operating methods that may lead to difficulties or inconveniences, are sufficient to prejudice some gas makers, even before a trial is made.

The superintendent who is about to try a new fuel, especially one that is so different from ordinary practice as bituminous coal, must fit his method of introducing the innovation to the temperament of his operators, realizing that for good results the cooperation of the gas makers must be obtained. An experienced gas maker senses every change in the behavior of his machine and this peculiar understanding can be utilized to advantage if the more visible conditions are borne in mind at the same time. This paper does not propose to tell the superintendent how to handle his men, but merely suggests how essential to success is their cooperation.

USE OF COAL AND COKE MIXTURES.

When the Streator experiments were begun, it was thought best to start with a fuel of known properties and work gradually to the unknown fuel; therefore at the start a run of about one week was made with retort coke of the type that had been used in the Streator plant for some months, the operating conditions being fairly well established. The coke that happened to be on hand was not of good quality; it was rather soft and gave an obstinate clinker unless an excess of steam was employed. The results obtained from this coke were not as good as those to be expected from a better grade and consequently are not given here as typical of coke fuel.

After the performance with plain coke had been studied for about one week, operation was commenced with a mixture of coal and coke. The coal first used was mined in Perry County, Ill.; its proximate analysis, sulphur content, and heating value are given in Table 8.

TABLE 8.—*Water-gas operation with mixtures of coal and coke as generator fuel.*

	Set A.					Set B.		Set C.
	100 per cent coke.	60 per cent coal.	70 per cent coal.	75 per cent coal.	100 per cent coal.	75 per cent coal.	80 per cent coal.	100 per cent coke.
Daily make ......corrected cu. ft	184,000	194,000	197,000	181,000	172,000	195,000	172,000	279,500
Make per hour...do....	23,000	21,500	23,200	22,200	21,200	26,000	23,400	25,400
Make per run....do....	2,706	2,896	3,130	2,780	2,606	3,305	3,046	3,630
Make per square foot grate area per running hour..........	1,840	1,690	1,860	1,775	1,700	2,080	1,872	2,016
B. t. u. of finished gas...	560	566	564	584	558	561	560	600
Cycle:								
Blow....minutes..	3	3	3	3	3	3	3	3
Run.........do....	4	4	4	4	3½	4	4	5
Blast pressure.......... .....inches of water..	18.5	20.0	18.5	19.5	17.5	17.5	15	19
Air per minute..cu. ft..	1,750	1,650	1,550	1,550	1,170	(?)	(?)	1,890
Air per 1,000 ft. of finished gas made ..cu. ft..	1,940	1,700	1,485	1,670	1,350	(?)	(?)	1,490
Steam per minute:								
Up runs.......lbs..	40	40	34	32	32	(?)	(?)	22.0
Down runs..do....	36	38	37	35	34	(?)	(?)	27.1
Steam per 1,000 ft. of gas made ....lbs..	42	55	45.3	48.2	41.1	(?)	(?)	33.0
Generator fuel per 1,000 ft...............lbs..	44.5	49.0	45.6	47	52	47	46.5	36.7
Oil per 1,000 ft..........	2.94	2.78	2.55	2.76	2.79	2.51	2.66	3.58
Up and down runs.....	2 up. 1 down.	2 up. 1 down.	1 up. 1 down.	1 up. 1 down.	2 up. 1 down.	1 up. 1 down.	1 up. 1 down.	
Daily operating time ....hours..	8	9	8.5	8.15	8.12	7.5	7.35	11.0

NOTE.—Sets A and B were located in the Streator plant. Set B, not being equipped with steam and air meters, was operated experimentally only when set A was down for repairs. Set C, in another plant, was operated with coke fuel, and results from this set are given for comparison; the fuel used was oven coke. All these sets had the same internal diameter, 4 feet.

The fuel mixture first used consisted of 55 per cent coal and 45 per cent coke. The coal was mixed by loading the charging bucket with fuel from separate piles at the same time, account having been kept of the amount of each fuel weighed in during the day. Each day the percentage of coal was increased a trifle, and operating conditions were varied to give the best results obtainable with each mixture. After about six weeks of operation 100 per cent coal was used. Table 8 gives typical results obtained with various mixtures of coal and coke.

This table does not indicate any very marked differences which can definitely be attributed to the proportions of coal and coke in the various mixtures. Consideration of all of the results obtained with various mixtures under approximately uniform conditions indicates, however, that the percentage of coal in the mixture does affect the production capacity to a certain extent, and in a way somewhat different from what might be expected.

Figure 9 is a curve showing the gas production per square foot of grate area per hour, with various percentages of coal in the generator fuel mixture. It will be noted that mixtures containing over 55 per cent of coal attain the maximum rate of gas production with about 70 per cent coal, the make decreasing with higher or lower percentages of coal.

Adjacent points on the curve are not necessarily determined by data obtained on successive days. The fact that the percentages of coal were varied during this period, however, leads to the belief that there is a proportion most favorable for mixing fuels. The fuel and oil efficiencies appear to be as favorable at this point as at any other, but the variation from day to day seems to be too much affected by other conditions to permit the plotting of a curve showing the effect of fuel proportions on these efficiencies.

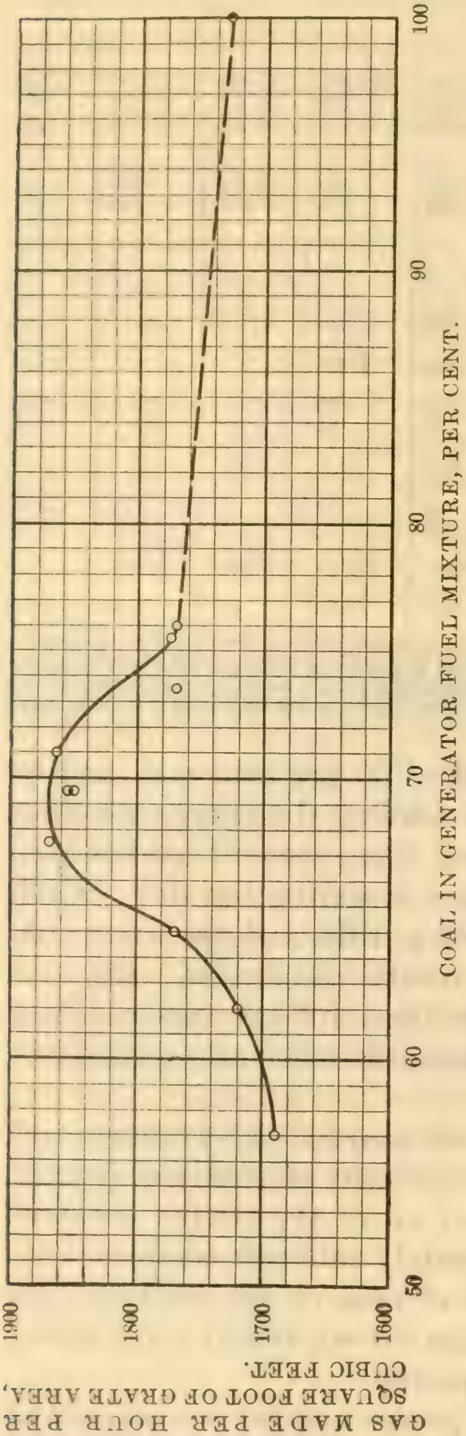

FIGURE 9.—Effect of percentage of coal in generator fuel mixture on capacity of set.

CONTROL OF ARCHING AND CAKING IN THE GENERATOR.

Arching can be readily prevented by making charges of normal size with greater frequency during the early part of the day's run. At Streator it was the practice to make one run in the morning before coaling; this will be discussed later. A normal charge was added after the first run and another after the third run. This method was continued until the fire was up to its usual operating level—level with the bottom of the take-off connection—as with coke. This depth of the fire was maintained by charges of normal size 35 to 45 minutes apart. The weight of each charge was about the same as that of the normal charge when coke was used. The resistance to the passage of air through the fire was found to be not excessive with this method of charging, the fire burned down uniformly, and there was no arching; consequently barring down was no longer necessary. When a coal with very strong coking properties is used and arching persists even under the above conditions, the difficulty can be remedied by making smaller but more frequent charges, although this necessitates opening the generator more frequently and causes a certain loss of operating time. In many plants the loss of time during coaling is excessive and could be reduced considerably by standardizing the movements of the various men participating. It will usually be found, however, that the time required for coaling with Central District coals is no greater than with coke.

REDUCTION OF CAPACITY WITH COAL FUEL, WITH THE USUAL OPERATING METHODS.

Experiments with coal in the Streator plant during operating practice similar to that used with coke soon demonstrated that little increase in the production capacity was to be expected without a radical change in operating methods. The results obtained with coal at Streator, therefore, tended to confirm those from other plants, although the capacity reduction was not so great as had been reported by some of them. The average make per square foot of grate area in the Streator plant was 1,700 cubic feet per hour with coal fuel, whereas makes of from 2,000 to 2,200 cubic feet per hour could have been reasonably expected with coke of good quality. A reduction in capacity of 20 to 25 per cent was therefore indicated. To remedy the conditions that cause decreased capacity and disturb the heat balance in the set, the so-called "blow-run" method was devised. This method will be discussed on page 62.

AIR PURGE.

In most plants using coal fuel, the practice is to purge out the gas remaining in the set at the end of the steam run with blast gas. This is accomplished by opening the generator blast valve, after shutting off the steam, several seconds before the stack valve is opened. The generator blast gas formed displaces the residual gas in the set. That this procedure is sometimes advantageous is evident from a consideration of the composition of the gas remaining in the set at the end of the steam run. The following is a typical analysis of a generator gas produced with coal during the last minute of the steam run:

Analysis of generator gas, 319 B. t. u. per cubic foot.

	Per cent.
CO_2	12.2
Ill	.2
O_2	.0
CO	27.2
CH_4	5.2
H_2	53.2
N_2	2.0
Total	100.0

The gas leaving the set during the purge is usually richer than this, due to the presence of illuminants remaining from the cracking of some residual oil that may not have been entirely decomposed during the earlier portion of the run.

This residual gas is worth saving if it can be purged out of the set by blast gas within a reasonable time and if care is taken that the purge is not so prolonged that not only the residual gas but some lean blast gas passes on to the holder. The importance of limiting the duration of the purge very carefully is evident from the composition of the gas formed in the generator at the beginning of the blow. The following is a typical analysis of blast gas 52.5 B. t. u. sampled at the generator lid at the beginning of the blow:

Analysis of generator gas, 52.5 B. t. u. per cubic foot.

	Per cent.
CO_2	17.5
O_2	.5
Ill	.2
CO	2.8
H_2	4.0
CH_4	2.5
N_2	72.5
Total	100.0

The mixture of only a small amount of this very lean gas with the finished gas in the holder would evidently offset any advantage that would be realized from saving the residual steam-run gas in the set. All operators do not understand this, as is evident from the fact that some are using air purges of such length that the amount of oil required per 1,000 cubic feet to enrich their blue gas is excessive. When the air purge is used, its duration should be carefully regulated so that the blast gas formed is just sufficient to purge out the good gas remaining in the set. The time needed for accomplishing this will vary in different plants according to the back pressure on the set and the blast pressure available. In fact, when the blast pressure is low and the back pressure is excessive, it may be impossible to purge the set by this method; if it is possible, it may take too much time to be advantageous. The correct length of air purge can usually be determined from the appearance of the flame at the stack when the stack valve is opened, the presence of yellow flame usually indicating that some fairly rich gas still remains in the set. At Streator an air purge of about 6 seconds was found to be satisfactory.

SMOKE PREVENTION.

The smoke given off by a gas works or other plant is naturally much more objectionable in some localities than in others. Some operators whose plants are situated in or near residence districts have feared the creation of a smoke nuisance from the use of bituminous coal as generator fuel more than any other objection raised to the use of such fuel. It is difficult to prevent the escape of smoke from any gas plant at times regardless of the fuel used. The possibilities of smoke productions are somewhat greater with bituminous coal than with coke, but by arranging the operating conditions it is possible to reduce smoke to a minimum, if not to abolish it entirely.

In a water-gas set, as in boiler plants or other furnaces, smoke from coal is caused by incomplete combustion. If conditions are so adjusted that combustion is complete at all times no smoke will be produced. Smoke is most difficult to control when a set is put into operation after a long lay-over; it follows, therefore, that the amount of smoke to be controlled is likely to be greater in plants operating but a small portion of the day than in those running nearly full time. If a large amount of green coal is put in the generator and blasted after the fire is cleaned in the morning following a lay-over of several hours a large amount of gas is evolved. This gas would perhaps be combustible by itself, but it is diluted by a considerable amount of carbon dioxide formed during the early part of the blasting period by the combustion of the incandescent fuel below. Considerable steam is, moreover, produced by the decomposition of the green fuel and by the evaporation of the moisture in the coal. Thus, there exists the condition of a lean gas mixture, carrying tarry vapors, passing from the generator into the carburetor and the superheater, and thence up the stack. The generator gases are difficult to ignite at the very beginning of the blast even with coke fuel, but since they are colorless and carry no tarry vapors no smoke is produced.

The problem with coal fuel is, then, to bring the gases as soon as possible to such a requisite degree of richness that they will burn at the prevailing temperature in the checker chambers. This can be accomplished if the temperature of the generator fuel bed is maintained so high that a large part of the CO_2 formed in the zone of complete combustion is reduced to CO by the upper layers of the incandescent fuel. When a deep bed of incandescent coke is blasted, it soon produces combustible gases. Therefore the gas maker has two alternatives. He may start operation with coke, getting the fire hot and the generator gases lighted before charging any coal; or, if he desires to be entirely independent of coke, he can so arrange his operating cycle that considerable coked fuel from the previous day's run remains in the generator after the fire is cleaned. This latter necessitates retaining a sufficient fuel reserve from the preceding day on which to operate until the gases passing from the generator are rich enough to ignite.

The method adopted at Streator and found satisfactory was to take only one or two runs off the last coaling before a lay-over, and when no blow-run cycle was in use to blast the fire for 2 minutes before shutting down. No steam run followed the last blast in this case. By this method of operating, a bed of hot fuel was left beneath the fresh charge, practically all of it being converted into coke by the next morning. The generator lid was left slightly ajar overnight, and sufficient air entered there to burn the volatile given off by the coal. This device helped to maintain a constant temperature in the carburetor and the superheater, but there was no overheating of these chambers. After the fire was cleaned in the morning, which usually did not take more than 20 to 40 minutes, a considerable bed of fuel remained for starting operation. This fuel was blasted about 10 minutes. Within 1 to 5 minutes the gases were combustible and could be lighted in the carburetor. After one run, a normal size charge of coal was made, and in the subsequent blast little or no difficulty was experienced in igniting the gases and burning all or nearly all of the smoke. After the start-up period, but little difficulty should be encountered in overcoming the smoke nuisance if operating conditions are normal; that is, (*a*) if the generator is kept hot enough to produce combustible gas during the blast; (*b*) if the checkerwork is hot enough to ignite the mixture of this gas with the secondary air, as supplied by carburetor blast; and (*c*) if the combustible gas and carburetor air are properly mixed and in correct proportions.

Some of these conditions, when lacking, may be attained by changing the operating procedure. For example, if the heats in the carburetor and the superheater are too low, an increased amount of generator blast or a decreased amount of steam used during the run are obvious remedies. When the mixing of air and blast gases in the carburetor and the superheater is poor, it sometimes may be remedied by a rearrangement of the checkerwork spacing, or by some device in the secondary air inlets to the carburetor and the superheater that will cause the incoming air to mix more intimately with the blast gas from the generator. Such cases must have individual attention, and no specific suggestion that will cover all conditions can be given.

CONTROL OF CLINKER.

In order to keep the temperature of the carburetor and the superheater within limits consistent with efficient practice, it was necessary to oversteam the generator during the Streator experiments when the set was operated with coal and the methods commonly used with coke fuel were employed. This tended to prevent the clinker from forming, or at least made it rather brittle. Very little difficulty was experienced from clinker during the experiments, particularly after a desirable operating cycle was formulated. In the early stages of the work some difficulty was encountered with side clinker—"edgings"—but this source of trouble was soon eliminated by increasing the per cent of down runs, whereupon the clinker fused and no longer clung to the wall, but collected on the grate, from which it was easily removed. Barring down clinkers through the charging door was no longer necessary.

After the blow-run method of operation was adopted, the clinker formed was somewhat harder but never gave as much trouble as that from the coke formerly used in the Streator plant.

SELECTION OF COAL.

When a Central District coal is selected as generator fuel, many of the requisites for other generator fuels hold. For example, the coal should not break up much on handling and it should be as free as possible from ash. The sulphur content is also a very important consideration. Analyses of the coals used in Streator indicate that at least one-fourth of the sulphur present in the coal passes into the blue gas. For example, a coal containing about 1.57 per cent S gave 155 grains of H_2S per 100 cubic feet of the blue gas. The Texas oil used in the carburetor increased this amount to 200 grains per 100 cubic feet in the unpurified carbureted gas. In general, it seems probable that any plant not equipped to purify raw gas containing more than 200 grains of H_2S per 100 cubic feet, at the average rate of purification, should use a coal with a sulphur content not exceeding 1.5 per cent in the delivered coal. Illinois State Geological Survey Bulletin 23 gives[12] a list of the mines of the Central District that could probably furnish coal complying with this condition.

The size of coal required for water-gas manufacture is also important, as with the other fuels. Since nearly all Central District coals show the coking property in varying degrees, however, it is not possible to prescribe one size for all coals.

The stronger the coking property of a coal the greater is the tendency for the lumps to mat in the fire, bringing about conditions similar to those existing when a coal containing considerable slack is used. In the experiments at Streator large egg size (4 to 6 inches) gave satisfactory results. Some coals broke up more readily than others, so that there was considerable slack. Although it is possible to use coal containing considerable slack under favorable conditions of blast pressure, such fuel tends to obstruct the passage of air through the fire. Careful forking and the avoidance of unnecessary breakage in handling are therefore recommended.

Certain Central District coals tend to disintegrate somewhat during storage, especially if exposed to the weather. Therefore it seems inadvisable to store coal for water-gas manufacture longer than is necessary to maintain an adequate stock. When circumstances necessitate the storage of such coal, the purchase of a larger size than otherwise required may be advisable to make due allowance for disintegration and breakage. The larger sizes are also less liable to spontaneous ignition.

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[12] Cady, G. H., Mines producing low-sulphur coal: Bull. 23, Illinois State Geological Survey, Coop. Min. Ser., 1919, p. 9.

BLOW-RUN METHOD OF OPERATION.

Data obtained in tests showed that when coal is used as generator fuel it is desirable to increase the capacity and efficiency of operation by maintaining a higher temperature in the generator, by preventing excessive heating of the checker chambers by utilizing more of the heat stored in them, and by obtaining more of the volatile matter of the coal in the finished gas.

In order to accomplish these objects, the so-called blow-run method of operation was instituted. This was run as follows:

1. A blast was made of sufficient length (3 minutes, for example) to heat the carburetor and the superheater to the desired temperatures.
2. The superheater and carburetor blast valves were closed.
3. The stack valve was closed.
4. The generator blast was continued for a fraction of a minute (15 to 45 seconds), the combustible gas produced passing through to the holder.
5. The generator blast valve was closed and a regular steam run of suitable length (about 3½ minutes) was made, oil being admitted to the carburetor in the customary manner.
6. After the completion of the run, the generator blast was started and a purge of suitable length (6 to 15 seconds) was made into the holder before opening the stack valve.

The adoption of this cycle presented no special difficulties at the Streator plant. The gas maker had to work carefully at first to avoid operating the valves in the wrong sequence, but he soon became accustomed to the new procedure, and it was then performed quite as automatically as before. The effects of this operating method may well be discussed under the following heads: First, effect on generator conditions; second, effect on quantity and composition of finished gas; third, effect on carburetor and superheater conditions; fourth, effect on fuel and oil economy; fifth, effect on oil-cracking efficiency; and, sixth, effect on production capacity. Naturally, these are to a great extent interrelated.

EFFECTS ON GENERATOR CONDITIONS.

The effects of the blow-run method on conditions in the generator are undoubtedly the most important, for although certain ultimate results in capacity, economy, and quality of production are sought for, the generator is the key to the entire situation. This is evident from the fact that from 75 to 80 per cent of the finished gas is made in the generator.

The addition of 30 seconds to the time of blasting the generator fuel affected results decidedly. So far as could be observed from the appearance and behavior of the set, the average temperature of the fuel bed was materially increased, resulting in a greater make of blue gas per minute during the actual steam run. The quality of the blue gas was also improved. The following analyses exemplify this change in composition.

TABLE 9.—*Typical analyses of blue gas produced with coal fuel, with and without the blow-run cycle.*

[B. t. u. per cubic foot (calculated): With blow run, 337; without blow run, 314.]

	With blow run.	Without blow run.
Carbon dioxide (CO_2)	6. 5	7. 5
Oxygen (O_2)	. 2	. 2
Illuminants	. 7	. 2
Carbon monoxide (CO)	33. 1	32. 3
Methane (CH_4)	5. 2	4. 4
Hydrogen (H_2)	48. 9	49. 0
Nitrogen (N_2)	5. 4	6. 4
Total	100. 0	100. 0

The analysis of the blue gas made by the blow-run method does not include the gas actually made during the blow run, but illustrates the effect of this method on the quality of the gas produced during the steam run.

These two analyses represent typical differences in composition. The absolute analyses varied considerably according to conditions, including the temperature of the fuel bed, the amount of steam used, the length of the run, the length of blow run employed, and the quality of coal. Some analyses of the blue gas made during the first run after coaling gave calculated heating values as high as 354 B. t. u., while without the blow-run method 320 B. t. u. per cubic foot was the maximum obtained.

The analyses in Table 10 indicate the change in composition of the blue gas from run to run in the interval between two successive coalings.

TABLE 10.—*Analyses of blue gas produced during successive runs between coalings.*

Constituents.	Up run—First run after coaling (B. t. u.—353.4).	Down run—Second run after coaling (B. t. u.—341.6).	Up run—Third run after coaling (B. t. u.—336.2).	Down run—Fourth run after coaling (B. t. u.—322.3).
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Carbon dioxide (CO_2)	8. 5	5. 9	8. 0	8. 8
Oxygen (O_2)	. 0	. 0	. 0	. 0
Ill.	1. 0	. 6	. 3	. 2
Carbon monoxide (CO)	32. 0	32. 2	30. 2	28. 3
Methane (CH_4)	5. 7	(5. 5)	5. 3	4. 7
Hydrogen (H_2)	51. 0	(53. 0)	53. 4	54. 6
Nitrogen (N_2)	2. 8	(2. 8)	2. 8	3. 4
Total	100. 0	100. 0	100. 0	100. 0

Each sample was taken at a fairly uniform rate during the run, but since the rate of gas production was diminishing from the beginning to the end of each run, each analysis does not represent the absolute average of the gas made during the run.

The increased fuel-bed temperature attained altered materially the nature of the clinker. The alteration was greater with some coals than with others. The coals having less fusible ash formed very little clinker when the blow run was not used. Under these circumstances, much of the ash did not fuse, but remained soft. As a day's run progressed, this ash accumulated, with the result that the active fuel bed became constantly shallower and the rate of gas production decreased very materially toward the end of the running time. With the blow run, on the other hand, the temperature was sufficient to bring nearly all of the ash down to the grate as clinker and permitted the maintenance of a deep fuel bed. Despite the fact that the clinker might be expected to offer more resistance to the passage of air blast than unfused ashes, production was maintained at a more normal rate in the Streator plant with the blow-run method than without it.

The blow-run method also helped to counteract smoke production. As stated in a previous section, one of the sources of smoke is a cold generator that produces a lean blast gas and tarry vapors resulting from the distillation of the coal. As soon as the generator becomes hot, richer blast gas is produced, which burns when ignited in the checker chambers and assists in consuming the tarry vapors that would otherwise leave the set as smoke.

EFFECTS OF BLOW RUN ON COMPOSITION OF FINISHED GAS.

The volume of blow-run gas in the finished gas depends upon the length of the blow run, the blast pressure available, and the back pressure against which the gas produced has to be forced. In other words, it depends upon the volume of air blast that can be forced through the fire (for the production of blow-run gas) per 1,000 cubic feet of finished gas made. Obviously, if the back pressure of the collecting main from the set to the relief holder were the same as the gas pressure at the outlet of the set during the blow run, no gas would flow from the set to the holder. This is a condition that may actually exist in some plants, especially those larger ones in which several sets are being operated with but one collecting main.

With the blast pressure obtainable in the Streator plant it was possible to force about 1,260 cubic feet of air per minute through the fire during the blow. During the blow run with the same coal, the air meter showed only 1,000 cubic feet of air per minute passing through the fire, although the air pressure at the base of the generator had increased from 18 to 28 inches, due to this resistance. From the composition of the gas, it is estimated that blow-run gas was produced from this volume of air at the rate of about 1,200 cubic feet per minute; therefore, with a 30-second blow run, about 600 cubic feet of gas, or approximately 18 per cent of the finished gas per run, was made during the blow-run period. It is, moreover, estimated, in lieu of any exact measurements, that the volume of the blow-run gas was equal to 25 to 30 per cent of that of the uncarbureted gas. The presence of this amount of blow-run gas in the finished gas, and the use of additional oil to carburet to the required standard, gives a gas of the composition shown in Table 11. An analysis of finished gas produced without the blow run is also shown for comparative purposes. These analyses are typical of the finished gas produced.

TABLE 11.—*Composition of finished gases.*

[B. t. u. (computed): With blow run, 574; without blow run, 569.]

	Without blow run.	With blow run.
CO_2	5. 8	4. 7
O_2	. 5	. 5
Illuminants	8. 7	10. 0
CO	27. 3	25. 5
CH_4	12. 5	13. 7
H_2	38. 0	27. 1
N_2	7. 2	18. 5
Total	100. 0	100. 0

The amount of oxygen is the same in both analyses (0.5 per cent). This oxygen was probably not in the gas originally, but was introduced into it when the sample was taken. Since one volume of oxygen is associated with about four volumes of nitrogen in the air it is evident that the actual amounts of nitrogen in the two gases were 5.2 and 16.5 per cent, respectively.

Analyses show that the blow run does not introduce air as such into the gas; accordingly, there is no danger of making an explosive mixture in the holder or mains.

Assuming that the heating value of the two gases is identical and that it is economically feasible to use the blow run in a given case, there appears to be no important reason, from the utilization standpoint, why the nitrogen content should be objectionable. Criticism of the presence of inert material in the gas is usually based upon the theoretical temperature usually called the "flame temperature" that could be obtained if all the heat from burning the gas were used to heat the products of combustion only. This flame temperature (as computed mathematically from the gas analysis, using the commonly accepted values for specific heats of the combustion products at high temperatures) is usually lower in the presence of appreciable amounts of inert substances, since it must be assumed that the latter are heated with the combustion products, although they do not contribute heat. Such computations applied to the above analyses give "flame temperatures" of 3,560° F. for gas with the blow run and 3,600° F. for gas without the blow run, differing from each other by only about 1.7 per cent. When it is considered that most of the gas is burned in appliances and used where the heated material attains a temperature far below the calculated flame temperature, it is evident that the transfer of heat from the gases to the heated material would be little affected by such small differences in the theoretical flame temperature. This difference becomes still more negligible when it is considered that with average operation less than 50 per cent of the heat of combustion usually passes into the material heated. The investigation committee of the Institution of Gas Engineers (British)[13] reported that its investigations in the utilization of gases of various grades and compositions indicate that the effect of the presence of 20 to 25 per cent of inert substances on combustion of gases having a heating value of more than 500 B. t. u. is practically negligible.

As will be noted from the analyses, the percentage of illuminants is higher in the gas made with the blow-run cycle. This is to be expected, since more oil is required to maintain a given standard. No evidence, however, was gathered from the experiments at Streator that the gas was any more stable with one method than with another. The unseasonably warm weather during the course of the experiments made the determination of condensation losses difficult. It might be stated that while the experiments were in progress at Streator there was no report by the company of complaints arising from the quality of gas furnished to consumers.

EFFECTS OF BLOW RUN ON CARBURETOR AND SUPERHEATER.

An attempt to bring the generator to a good working temperature with coal fuel usually necessitates a length of blow period that overheats the carburetor or superheater, unless much of the combustible blast gas is burned at the stack, or heat is taken from these chambers by overblowing them. Increasing the blasting time by the introduction of a blow run, even though this blow run be but a fraction of a minute in duration, assists materially in heating the generator, but does not add any appreciable amount of heat to the carburetor and superheater, since the gas produced in the generator during the blow run is not burned in these chambers and the temperature of this gas as it leaves the generator is probably lower than that of the checkerwork.

In order to illustrate the changed conditions brought about by the use of the blow-run method and to point out the more prominent factors involved in the selection of a proper cycle, the two sample tests presented as Table 12, embodying some of the results obtained during the experiments at Streator, are considered. Column A shows the operating figures without a blow run and column B the figures with a blow run.

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[13] Gas World, vol. 69, Oct. 19, 1918, p. 1787.

TABLE 12.—*Typical results showing some of the effects of the blow-run method of operating.*

	Test A (without blow run).	Test B (with blow run).
Blue gas [a] cu. ft. per 1,000 ft.	815 (314 B. t. u.)	625 (337 B. t. u.)
Blow-run gas do.		180 (153 B. t. u.)
Oil gas [a] do.	185 (1,670 B.t.u.)	195 (1,656 B.t.u.)
Total do.	1, 000	1, 000
Make per run cubic feet.	2, 700	3, 500
Oil per run gallons.	7. 7	10. 5
Oil per thousand feet do.	2. 85	3. 05
Per cent of blue gas in finished gas	81. 5	62. 5
Per cent of blow-run gas		18
Gas burned at stack	Considerable.	Very little.
Cycle	3-minute blast, 4-minute run.	3-minute blast, ½-minute blow run, 3½ minute run.
B. t. u. of finished gas	565	565
Total blue gas made per run cubic feet.	2, 200	2, 190
Blue gas made per minute of steam run, allowing 15 seconds of running time for change of valves cubic feet.	586	675
Air per thousand feet	1, 400	1, 265
Steam per thousand feet	43. 2	35. 3

It is evident from the figures in Table 12 that more generator gases are produced for carbureting per run in test B than in test A. Naturally, this requires that more oil be admitted to the carburetor during the run represented by test B. The increased amount of oil absorbs more heat from the checker chambers. This requires the use of more generator air blast (blast plus blow run) with the resulting hotter generator, and at the same time permits practically all of the combustible blast gas to be burned in the checker chambers.

It can be said, in general, that when the same amounts of air and steam are used, respectively, per minute in each case, the ratio of the total blasting time (including the blow run) to the length of the steam run must be greater with the blow-run method than without it. Although a blow run of almost any desired length may be used with a given air-blast condition, it must be remembered, in selecting a blow run of specified length, that as the duration of the blow run is increased, a greater quantity of gas is produced for carbureting. Hence, more oil is required per run for enrichment, correspondingly more heat is absorbed from the checker chambers, and therefore a longer blast or a shorter steam run is required in order to maintain the heat balance throughout the set. When the blow run is being tried for the first time, there is sometimes a tendency to choose such a cycle that the checker chambers do not become hot enough to crack and fix the oil properly. This usually arises from failure to understand the nature of the changed conditions just discussed. The tendency when this condition occurs is to shorten the blow run, whereas greater capacity and a better heat balance could frequently be obtained by lengthening the blast period, increasing the blast pressure, or shortening the steam run.

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[a] The exact percentages of blue gas and oil gas are not known and the figures given here are estimates only.

EFFECTS OF BLOW RUN ON FUEL AND OIL ECONOMY.

In the discussion of the effect of the blow run on the composition and the quantity of blue gas produced, it was pointed out that a certain volume of blow-run gas (the richer blast gas produced at the end of the blasting period) is saved by passing it into the relief holder. In composition, this gas resembles that made in a producer especially designed for bituminous coal. One might expect that the composition of this gas would vary greatly from blow to blow, as the fresh fuel introduced during the charge is distilled and is gradually transformed into coke. This transformation is much more gradual than might be expected, and the following analyses of the blow-run gases for each successive blow between coalings illustrate the comparative uniformity of the gas produced over successive blow-run periods:

Table 13.—*Analyses of blow-run gas—successive runs.*

Constituents.	First blow run after coaling.	Second blow run after coaling.	Third blow run after coaling.	Fourth blow run after coaling.	Average.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
CO_2	2.1	2.7	1.9	2.4	2.28
Illuminants	.6	.4	.3	.1	.35
CO	28.4	26.2	29.9	27.1	27.90
CH_4	3.0	3.3	3.0	3.9	3.30
H_2	5.5	7.5	5.1	6.2	6.07
N_2	60.4	59.9	59.8	60.3	60.10
Total	100.0	100.0	100.0	100.0	100.00

These analyses give calculated heating values for the successive blow runs of 157, 152, 153, and 149 B. t. u., respectively, the average being 153 B. t. u. The utilization of the blow-run gas of this average heating value means a saving of generator fuel. In some of the tests at Streator, the volume of blow-run gas amounted to approximately 18 per cent, or 180 cubic feet out of every 1,000 cubic feet of finished gas made. The heat in this amount of gas would be 27,500 B. t. u., or the equivalent of about 2.3 pounds of coal. Over a period of several days' operation, the generator fuel averaged about 5 pounds less per 1,000 cubic feet of finished gas with the blow-run method than without the blow run, despite the fact that the increased capacity obtained in the former case reduced the daily operating time nearly 20 per cent, thereby making longer lay-over periods during which radiation and convection losses were taking place.

Part of the total economy obtained when operating with the blow-run method is due to a decreased amount of fuel consumed by the air blast, and part of it is due to a more efficient utilization of the steam during the run.

The amount of fuel consumed during the blasting of the generator is roughly proportional to the volume of air blast used. It is not always exactly proportional, since the two following reactions take place in greater or less degree, according to the initial temperature of the fuel, the rate of blast, and other factors:

1. $C+O_2=CO_2$.
2. $2C+O_2=2CO$.

The carbon consumed according to reaction 1 is only half as great as that consumed by reaction 2, using the same amount of air.

The amount of generator air blast used per 1,000 cubic feet of finished gas is noticeably less when the blow-run method is used than when it is not. The amount of air used per 1,000 cubic feet in test B of Table 12 is 90 per cent of that used per 1,000 cubic feet in test A. If reactions 1 and 2 were taking place in the same proportions in tests A and B, the fuel consumed during the blast (not the total generator fuel per 1,000 feet) would be proportional to the air used per 1,000 cubic feet. In these examples, the indications are that this was approximately true and that the fuel consumed during the blast per 1,000 cubic feet of finished gas made in test B was 90 per cent of that consumed per 1,000 in test A. This is derived as follows:

$$\frac{\text{Air per 1,000 cubic feet in test B}=1{,}265\text{ cubic feet}}{\text{Air per 1,000 cubic feet in test A}=1{,}400\text{ cubic feet}}\times 100\text{ per cent}=90\text{ per cent.}$$

The air used in the blow run was included in the air per 1,000 feet (1,265 cubic feet).

This factor (90 per cent) is emphatically not a constant, but would vary under different conditions. It does not pertain to the total generator fuel per 1,000 feet, but only to that part consumed during the blasting of the generator.

The amount of steam used per minute of run in both tests was approximately the same, but the steam used per 1,000 cubic feet of finished gas was decidedly less with the blow-run method than without it. The amount of blue gas made per minute in test B was much greater than that made in test A, although the total blue gas made per run was about the same in each case. Since the total steam used for the production of the same amount of blue gas was less in test B, an evident saving is made by reducing the amount of fuel consumed by the steam during the run. Inasmuch as the same amount of gas is produced in test B as in test A, with 7 pounds less of steam per 1,000 feet, it may be assmued that the saving per 1,000 feet is equivalent at least to the amount of heat required to raise the 7 pounds of steam to the temperature of the effluent gas—approximately 1,350° F. This would amount to about one-third of a pound of generator fuel per 1,000 cubic feet of gas made.

The total heat absorbed by the 7 pounds of steam passing through the fire and being heated to 1,350° F. is approximately 3,641 B. t. u.

The hotter generator maintained with the blow-run method may occasionally result in a further saving of fuel, in that there is usually less likelihood of the fuel passing through the fire unconsumed.

Since the data in specimen tests A and B are taken from results obtained in a plant operating only 6 or 7 hours per day, it is impossible to predict accurately from the information available what the relative fuel economies with these two methods would be in plants operating full time. The indications are, however, that a material fuel saving could be expected with the blow-run method.

The oil economy is also affected by the use of the blow run, the extent of this effect depending upon the length of the blow-run period and the amount of gas produced during that period. The amount of oil required per 1,000 cubic feet of gas to maintain a certain standard in a given plant would be difficult, if not impossible, to predict with certainty unless many factors were known, such as the kind of oil, the quality and quantity of blow-run gas and blue gas made, and weather conditions. The economy possible when the blow run is used can be determined only by trial.

The mixture of blue gas and blow-run gas produced by the blow-run method is not as rich as the blue gas produced without the blow run; therefore, more oil is required for enrichment in making 1,000 cubic feet of finished gas in the former case. In general, it may be said that the oil required per 1,000 cubic feet of finished gas increases as the percentage of blow-run gas in the mixture increases. The increased amount of oil required, however, is not directly proportional to the percentage of blow-run gas, since, as has already been shown, the quality of blue gas produced is richer with the blow-run method.

The quality of the coal used also affects oil economy. The volatile matter of some coals has a higher heating value than that of others, and this affects the quality of both the blue gas and the blow-run gas. Under the conditions existing at Streator, a heating-value standard of 565 B. t. u. was maintained a mile from the plant with 3 to 3.05 gallons of Texas oil per 1,000 cubic feet of gas, using the blow run, against about 2.85 gallons per 1,000 feet, without the blow run.

The length of blow run used during the experiments varied from 15 to 45 seconds and the oil varied accordingly. It is noticeable that while the oil per 1,000 cubic feet using coal is greater with the blow-run method than without it, the amount of oil used per 1,000 cubic feet with coke fuel and without the blow run is still greater.

The oil economies obtainable show considerable seasonal variation. More of the condensable heat-producing constituents of the gas are chilled out in cold weather than in the summer months. This requires that a greater quantity of oil per 1,000 cubic feet of finished gas be used in winter. The figures given above were obtained in the late autumn.

COMPARATIVE EFFICIENCY OF OIL CRACKING WITH COKE AND WITH COAL FUEL.

The figures presented for oil consumption per 1,000 feet, operating with and without a blow run, are the results of more than one day's run and are not a selection of the best figures obtained in any series of tests. They have, in the main, been duplicated in other plants and are probably accurate enough for all practical purposes.

The cracking efficiency of the oil used, however, can not be stated with such accuracy. In attempting to derive a figure that will express oil-cracking efficiency, it is necessary to know the exact amount of oil gas present in 1,000 cubic feet of finished gas and to ascertain its heating value. In the Streator experiments, no attempt was made to determine this. However, the blue gas and the blow-run gas were analyzed and the volumes estimated from the available figures. The volume and heating value of the oil gas (gas from oil cracking) can be approximated by difference. Typical data are given in Table 14. The cracking efficiencies presented in this table are so nearly alike that without additional information it is impossible to say definitely that the oil cracks more completely into gas with coke fuel than with coal. However, at the present time it is the author's belief that these efficiency figures are representative of the results obtained. It is not improbable that the great excess of steam used when operating with coal and without the blow run had a beneficial effect on the oil cracking, resulting in the increased oil-cracking efficiency shown. Although in some instances a greater amount of carbon is deposited in the carburetor when coal fuel is used, there is little question that some of this results from the carbonization of the tarry matter distilled from the coal in the generator; therefore, this deposit can not be taken as evidence of a decreased efficiency of oil cracking.

TABLE 14.—*Oil efficiencies with coal and with coke fuel.*

	Test A.	Test B.	Test C.
Fuel used	Bituminous coal	Bituminous coal	Coke.
Blow-run cycle	None	Yes	None.
Cycle	3-minute blast, 4-minute run.	3-minute blast, ½-minute blow run, 3½-minute steam run.	3-minute blast, 4-minute steam run.
Oil:			
Amount used per 1,000 cubic feet of finished gas, gallons.	2.85	3.05	3.15.
Gravity, pounds per gallon.	7.3	7.3	7.3.
Weight per 1,000 cubic feet, pounds.	20.8	22.265	22.995.
Total heating value, B. t. u.	416,000	445,300	459,900.
Gas:			
Blue gas made per 1,000 cubic feet, cubic feet.	815 (314 B. t. u. per ft.).	625 (337 B. t. u. per ft.).	790 (292 B. t. u. per ft.).
Blow-run gas made per 1,000 cubic feet, cubic feet.		180 (153 B. t. u. per ft.).	
Oil gas made per 1,000 cubic feet, cubic feet.	185 (1,670 B. t. u. per ft.).	195 (1,656 B. t. u. per ft.).	210 (1,592 B. t. u. per ft.)
Total gas made, cubic feet	1,000	1,000	1,000.
B. t. u. per foot of finished gas.	565	565	565.
Total heat of combustion, per 1,000 cubic feet of finished gas, B. t. u.	565,000	565,000	565,000.
B. t. u.:			
Furnished by the blue gas	255,600	210,625	230,680.
Furnished by the blow-run gas.		27,540	
Total in the oil used	416,000	445,300	459,900.
To be supplied by the oil per 1,000 cubic feet.	309,400	326,835	334,320.
Oil in carbon, tar, condensable products.	106,600	118,465	125,580.
Efficiency of oil cracking, per cent.	74.4	73.4	72.7.

In the change from coke to coal fuel, the following variables, which affect oil cracking, are altered: Atmosphere in which the oil is cracked, time and intimacy of contact of the oil vapor with the hot checker bricks, volume of oil used per 1,000 feet of finished gas, volume of oil used per 1,000 feet of blue gas, make per unit of time, and heat absorbed from checker chambers during the run.

It is evident that the problem of checking cracking efficiency by theoretical considerations is therefore very complex.

EFFECT ON CAPACITY.

The blow-run method was first worked out with the hope of increasing the capacity with coal as fuel approximately to that attained with coke. The blow run is recognized to have practical limitations and should only be employed to an extent consistent with reasonable economy of fuel and oil. As stated, it was found that with a blow run of reasonable length the oil per 1,000 cubic feet of finished gas was less than that required when coke fuel was used. The amount of coal fuel per 1,000 cubic feet was less with the blow run than without it. At the same time, the capacity was increased until it approached that attained with coke fuel. Assuming that the blast and steam conditions are adequate and that pressure conditions are suitable, the blow run could be carried still further in an emergency, but of course the use of it to an excessive degree would necessitate the use of more oil per 1,000 cubic feet to enrich the increased volume of lean gas. The heat required to crack the oil properly when such an excess is used might exceed the heat-storage capacity of the checkerwork. Under such conditions, part of the oil would inevitably pass through the set undecomposed. An excessive employment of the blow run, necessitating the use of a greatly increased amount of oil per run, might be very disadvantageous under some conditions, on account of an increased formation of carbon in the checkerwork, a fact more noticeable with some gas oils than with others. The standard of gas quality to be maintained might be another limiting condition at times. It would probably be impracticable to meet a high candlepower standard with this method. With the increasing tendency toward lower heating-value standards and the abolition of candlepower standards, the field for the application of this method is greatly widened.

The back-pressure conditions in the Streator plant did not make practicable the introduction of a portion of the oil during the blow run, since the blast pressure was not sufficient to produce as much blow-run gas when the pressure in the set was increased by the addition of oil. Had it been practicable to do so, it seems likely that an advantage would have been realized. The oil could have been admitted more slowly, the concentration of oil gas in the checker chambers would not have been so great, and the oil cracking efficiency might have been greater. Whether the advantages from decreased concentration would be offset by a change in the efficiency of oil cracking in an atmosphere of blow-run gas, can not be stated. The rate of make during the run, including the blow run, is shown in Figure 10. Relief-holder readings were taken every 15 seconds and the readings plotted. The first drop in the curve, at the end of 30 seconds, indicates the change from blow run to steam run.

USE OF COAL AND COKE MIXTURES WITH THE BLOW RUN.

If a sufficiently large make of gas per hour can not be obtained with 100 per cent coal and a blow run of reasonable length, it may be increased by using a fuel mixture (coal and coke) containing up to 25 per cent coke with a blow run of suitable length, depending upon the air blast available, the quality of gas to be maintained, and the hourly make desired. During a run of a few days at the Streator plant, with 25 per cent coke and a 30-second blow run, the hourly capacity was increased about 6 per cent over that attained during the days immediately preceding, when 100 per cent coal was used. The blast pressure was practically the same in both cases, but the air passing through the fire per minute during the blast was somewhat greater when the mixed fuel was used, probably the chief factor in causing the increased make. During the few days when this combination of conditions was tried, there was no perceptible increase in the amount of oil used per 1,000 cubic feet of gas to maintain practically the same heating value.

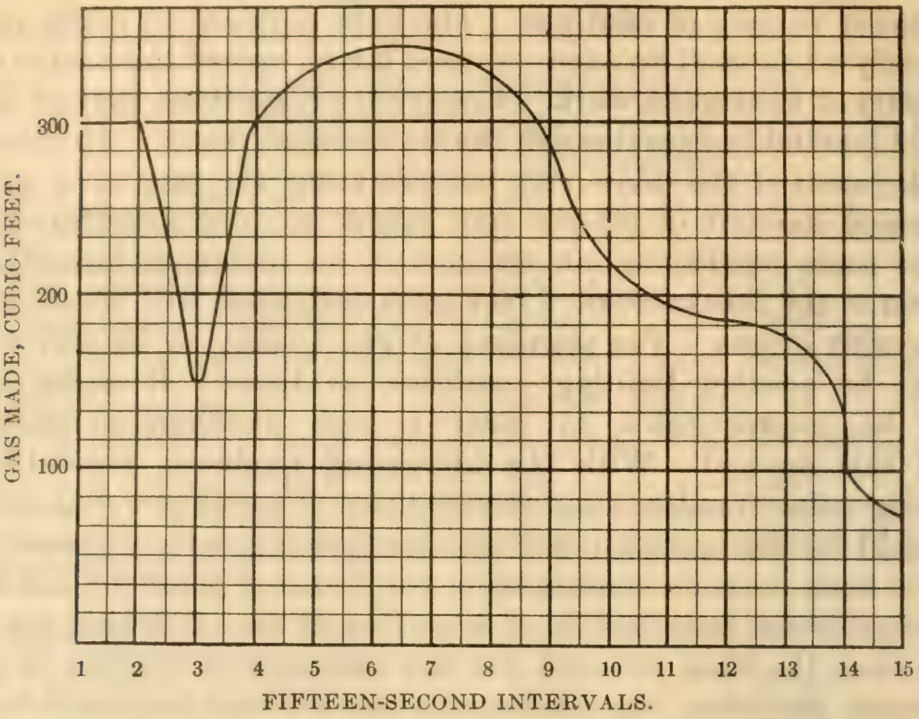

FIGURE 10.—Variation of gas made during run as determined from rise of relief holder during successive 15-second intervals.

TABLE 15.—*Conditions and operating results with various coals in the Streator plant.*[1]

Coal used.	Perry County, Ill.		Franklin County, Ill.		Williamson County, Ill., A.		Williamson County, Ill., B.	Retort coke.[2]	Indianapolis oven coke.[3]
	With blow run.	Without blow run.	With blow run.	Without blow run.	With blow run.	Without blow run.	With blow run.		
Daily make (corrected) ....cu. ft..	165	155	180	162	163	172	177	184	279
Make per hr. (corrected) ....cu. ft...	26	21.7	28	23.2	25.6	23.4	24.8	23	25.4
Make per hour per square foot grate........	2,069	1,735	2,260	1,860	2,048	1,875	1,980	1,840	2,016
Make per run (corrected) ....cu. ft..	3,374	2,656	3,600	2,945	3,281	2,831	3,160	2,706	3,630
Cycle:									
Blow..........minutes..	3	3	3	3	3	3	3	3	3
Blow run.......seconds..	30	0	30	0	25	0	30	0	0
Steam run.....minutes..	3.4	3.9	3.4	3.9	4	3.9	3.9	4	5
Air purge.......seconds..	6	6	6	6	6	6	6	0	0
Up and down runs..........	1 to 1	2 to 1	1 to 1	1 to 1	1 to 1	1 to 1	1 to 1	2 to 1	....
Blast pressure during blow ....inches..	17.5	18	18	18	18	18	18	16	19
Air per minute during blow........cu. ft..	1,258	1,240	1,096	1,050	1,130	1,100	1,210	1,750	1,890
Air per minute during blow run........cu. ft..	1,016	0	975	0	980	0	800	0	0
Air per 1,000 cubic feet finished gas..........cu. ft..	1,265	1,401	1,050	1,070	1,184	1,180	1,275	1,940	1,490

[1] These results were obtained with a set having a generator of 4 feet internal diameter.

[2] This was the coke formerly used at the Streator plant. On account of the obstinate clinker, excess steam had to be used. It gave inferior results.

[3] These results were obtained in another plant with a good grade of oven coke. They are given for comparison.

TABLE 15.—*Conditions and operating results with various coals in the Streator plant*—Continued.

Coal used.	Perry County, Ill.		Franklin County, Ill.		Williamson County, Ill., A.		Williamson County, Ill., B.	Retort coke.	Indianapolis oven coke.
	With blow run.	Without blow run.	With blow run.	Without blow run.	With blow run.	Without blow run.	With blow run.		
Steam per minute:									
Up run..............lbs..	35	31	35	32	35	34	34	40	22
Down run...........do..	33	33	37	34	34	32	32	36	27
Steam per 1,000 cubic feet finished gas.............lbs..	34.2	47	33.7	45	37.2	45.5	40.7	42	33
Generator fuel per 1,000 cubic feet..................lbs..	47.3	52	42.3	48.8	43	46	44.5	44.5	36.7
Average weight of charge ....lbs..	644	600	600	700	700	560	606	800	....
Charging intervals.....runs..	5	5	5	5	5	5	5	5	....
Oil per 1,000 cubic feet .... gallons..	3.04	2.84	3.02	2.78	3.24	2.97	3.06	2.94	3.58
Oil per run...............do..	10-11	7.5	10-12	8-9	10-12	8.5	10-11	8	13
Daily operating time.hours..	6.35	6.9	6.45	7	6.36	7.35	7.15	8	11
B. t. u. of city gas, 1 mile from plant..................	562	565	565	556	570	578	567	560	600
Hydrogen sulphide in unpurified gas .....grains per 100 cu. ft..	150	150	160	160	200	200	420	100	....
Nature of clinker............	(4)	(5)	(6)	(6)	(6)	(6)	(7)	(8)	....

[4] Hard, some edgings, brittle.

[5] Rather soft.

[6] Hard on grate, easily removed.

[7] Hard, brittle, easily handled.

[8] Hard, excess steam necessary to make workable.

OPERATING RESULTS AT STREATOR.

Table 15 includes typical operating results obtained with various coals during the Streator experiments. These results are not averages, since the conditions were frequently changed during the course of the experiments to get what seemed to be the best combination, and in the course of such experimenting there were tried some operating methods that were obviously unsuitable, since they gave very poor results. Moreover, such unforeseen factors as low blast pressure and low steam pressure occasionally caused a poor record for a day, yet could in no way be attributed to the nature of the coal under test. Therefore, while neither the best nor the poorest results are given, and the results tabulated are not strictly averages, in the judgment of the authors they represent typical performances possible of duplication under plant conditions similar to those at Streator.

COALS USED IN TESTS.

All the coals used in obtaining these results were from the southern Illinois field. With the exception of the Perry County coal, which had been used in the Streator plant for some time prior to the experiments, one carload only of each coal was tested. The fuel consumption of the plant was only about 4 tons per day, therefore each carload of coal was sufficient for a run of about 10 days, varying according to the percentage of the coal that was too fine for the generator. This latter was, however, used as boiler fuel.

The coal forked from each carload was sampled and the samples subsequently analyzed in the laboratories of the University of Illinois at Urbana. The results of the analyses are given in Table 16 following:

TABLE 16.—*Analyses of coals used in Streator tests.*

Source of coal.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Total.	B. t. u.	Total sulphur.
Perry County, Ill..	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*
As received	7.77	33.86	49.30	9.07	100.0	11,827	1.29
Air dry	2.36	35.85	52.19	9.60	100.0	12,514	1.37
Moisture free	....	36.72	53.45	9.83	100.0	12,816	1.40
Franklin County, Ill.:							
As received	9.98	32.54	47.49	9.99	100.0	11,419	1.25
Air dry	2.30	35.32	51.54	10.84	100.0	12,393	1.36
Moisture free	....	36.15	52.75	11.10	100.0	12,684	1.39
Williamson County, Ill., A:							
As received	7.32	31.82	50.42	10.44	100.0	11,806	1.57
Air dry	2.94	33.33	52.80	10.93	100.0	12,364	1.64
Moisture free	....	34.34	54.40	11.26	100.0	12,738	1.69
Williamson County, Ill., B:							
As received	6.40	33.26	50.68	9.66	100.0	12,109	2.29
Air dry	2.84	34.52	52.61	10.03	100.0	12,569	2.38
Moisture free	....	35.53	54.15	10.32	100.0	12,936	2.45

In addition to the tests of the coals named in the above table, short tests were made with two other coals, one from La Salle County, Ill., the other from Sullivan County, Ind. Of these, the La Salle County coal was found to be so high in sulphur that operation with it was discontinued after about three hours. During this short run, the indications were that the coal was inferior in its gas-making qualities, since the fire burned down more rapidly than with the other coals, yet less gas seemed to be produced.

The Sullivan County, Ind., coal also was tried for but a short run. It gave a higher sulphur content to the gas than most of the Illinois coals although not so much as could not have been removed by the purifiers, had not the purifying capacity of the plant been already overworked by the use of some of the higher sulphur coals that were tried previous to this. Indiana coals from the same field have been successfully used for water-gas making, as will be shown a little later.

Of all the coals tested, that from Franklin County showed slightly the best general results, although it gave slightly more sulphur to the gas than did the Perry County coal. Its clinker was somewhat harder than that formed by other coals tested, and apparently fused at a lower temperature. The clinker from the Franklin County coal tended to form on the grate and to adhere less to the generator wall than that from the Perry County coal. Under the prevailing conditions, the harder clinker formed by this coal made the cleaning of the generator fire easier than with the other coals, since it held up the fire better. The resistence which this coal presented to the passage of air through the fire was distinctly greater than that of the Perry County coal. Nevertheless, a larger hourly make and better fuel economy were obtained with it. Its effect on the oil consumption was about the same as that of the Perry County coal.

The Perry County coal showed slightly less sulphur in the gas than any of the other coals tried. A much longer run was made with this coal than with the others, and it was used in obtaining the results already given with fuel mixtures. Owing to the extensive experimenting with this coal, its peculiarities were better known than those of the other coals, and the data collected concerning it therefore made a good standard with which to compare them. The Perry County coal was considered very satisfactory for water-gas manufacture.

The Williamson County coal, A, did not give as good results with the blow-run method of operations as did the coals already discussed. Its slightly lower percentage of volatile matter and its higher ash content seem to be responsible for this. On the other hand, its higher fixed carbon content seemed to make it more adaptable to the usual method of operating—without the blow run—than the other coals, and with that method it gave a slightly greater hourly output.

The clinker formed from its ash resembled that of the Franklin County coal, its resistance to the passage of air blast was between that of the Franklin County and Perry County coals, and its sulphur content was somewhat higher than either.

The Williamson County coal, B, contained so much sulphur that it would not generally be considered available for gas making under present conditions, therefore only a short run was made with it and no very definite idea of its gas-producing qualities can be formed. The indications are that generally it would be a little inferior to the other coals tried.

SULPHUR IN GAS.

The tests at Streator indicate that, other conditions remaining the same, the hydrogen sulphide in the unpurified carbureted gas is roughly proportional to the per cent of total sulphur in the coal. In Figure 11 this relation is illustrated. There was, however, one marked exception among the seven coals tested, although this might have been due to the fact that the test with this coal was too short to permit many hydrogen sulphide tests to be made on the gas. Whether a similar relation would hold with other coals can not be stated. In all the tests, the same kind of oil was used and operating conditions were fairly similar, so that the percentage of sulphur in the coal might reasonably be expected to be the prime factor affecting changes in the sulphur content of the gas. However, different conditions in washing and cooling the gas alter the amount of H_2S in the unpurified gas; therefore the same relation between sulphur in coal and sulphur in gas would not exist if these conditions were changed.

USE OF BITUMINOUS GENERATOR FUEL IN PLANTS OTHER THAN STREATOR.

The work done at Streator has led to the use of bituminous coal fuel in water-gas manufacture at a number of plants in various parts of the country. Moreover, a number of companies who used bituminous coal in their plants prior to the Streator tests have been interested in comparing their own operating results with those obtained at Streator. Some of the results obtained by such plants in different parts of the country under various operating conditions with different coals are presented in Table 17. Some of these data show results obtained with eastern gas coals, although a majority of the plants mentioned used Illinois or Indiana coals.

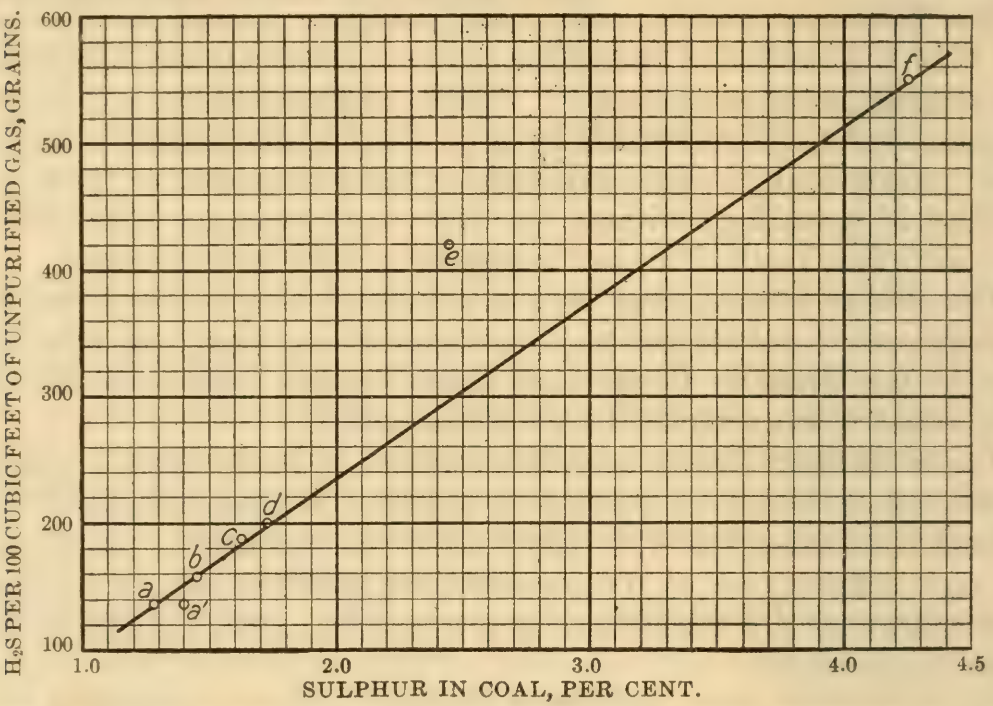

FIGURE 11.—Relation of sulphur in coal to hydrogen sulphide in unpurified carbureted gas. Key to sources of coal: *a*, Perry County, Ill. (old coal); *a'*, Perry County, Ill. (new coal); *b*, Franklin County, Ill.; *c*, Sullivan County, Ind.; *d*, and *e*, Williamson County, Ill.; *f*, La Salle County, Ill.

TABLE 17.—*Operating conditions and results with bituminous generator fuel in plants other than Streator.*

Plant	A	B	C	D	E	F	G
Internal diameter of generator......feet..	6	4	6½	5	8½	4⅔	....
Kind of fuel used.	Clinton County, Ind., bituminous.	Franklin County, Ill., bituminous.	Perry County, Ill., bituminous.	Virginia bituminous.	50 per cent anthracite; 50 per cent eastern gas coal.	Harlan County, Ky., bituminous.	Franklin County, Ill., bituminous.
Daily make, in 1,000 cubic feet corrected.......	550	344	1,225	335	2,323	225	574
Daily operating time, including cleans...hours..	14.25	18	24	13.5	23.85	13	....
Cycle:							
Blow, minutes	3	3	2.66	3	3	4	3
Blow run, minutes....	.5	0	.33	0	0	.5	.5
Steam run, minutes....	3.25	4.9	3.84	4	4	3.75	3.75
Purge, minutes.......	.25	.1	.16	0	0	.25	.25

TABLE 17.—*Operating conditions and results with bituminous generator fuel in plants other than Streator*—Continued.

Plant	A	B	C	D	E	F	G
Internal diameter of generator......feet..	6	4	6½	5	8½	4⅔	....
Kind of fuel used.	Clinton County, Ind., bituminous.	Franklin County, Ill., bituminous.	Perry County, Ill., bituminous.	Virginia bituminous.	50 per cent anthracite; 50 per cent eastern gas coal.	Harlan County, Ky., bituminous.	Franklin County, Ill., bituminous.
Blast pressure during blow, inches..........	17-20	16-24	....	....	....	14	17-20
Air:							
Per minute during blow, cu. ft.	2,800	1,250	....	....	10,000?	1,400	2,800
Per minute during blow run, cu. ft.......	....	0	....	....	0	1,200	....
Per 1,000 cu. ft. finished gas..cu. ft..	1,410	1,155	....	....	2,140	2,010	....
Percentage of up runs.............	33	66	....	....	....	66	33
Steam:							
Per minute up.....lbs..	60	25.8	....	40?	128	34	60
Per minute down..lbs..	60	28.8	....	40?	123	31	60
Per 1,000 cu. ft. finished gas....lbs..	34.6	42.5	....	48.4?	35.8	40.1	36.4
Make:							
Per running hour, cu. ft.	45,250	21,700	55,700	28,450	110,500	20,245	50,500
Per set hour, including cleans, cu. ft..........	41,600	19,300	52,100	27,130	98,000	19,200	45,840
Per run, cu. ft.	5,205	3,119	6,594	3,311	14,000	3,082	6,176
Per running hour per sq. ft. grate., cu. ft..........	1,600	1,736	1,688	1,445	1,950	1,190	1,785
Generator fuel per 1,000 cubic feet, lbs..............	43.4	43.4	41.9	42.29	33.57	46	39.14
Average weight charge.....lbs..	800-1,000	....	....	500	....	1,175	800-1,000
Charging interval, runs............	4-5	....	....	3	....	8-10	4-5
Oil:							
Kind used....	Texas 27°	Okla. 30-36°.	Texas 28°.	Okla. 32-34°.	Mex. 34°.	Texas 30°.	Texas 27°.
Introduced, minutes....	3	4½	3.5	3	3	4	3
Per 1,000 cubic feet. gallons.	3	3.22	3.19	2.90	2.94	2.90	3.07
B. t. u.:							
Amount in finished gas.	565	600	568	600	602	c. p. 18	565
Where record was taken..	Plant.	1 mile from plant.	Plant.	Plant.	Plant.	....	Plant.
Cleaning time per day...minutes..	69	120	94	40	160	60	69
Nature of clinker..	Hard, but easily handled.	Easily removed.	Hard, considerable edgings.	Brittle, close to grates.	Soft.	Mostly ash on grate.	....
Carbon in ash and clinker.........	Very little.	Considerable.	....	Practically none.	Considerable.	None.	....
Hydrogen sulphide, raw gas, grains per 100 cu. ft...........	200	....	150	70	....	....	....

An inspection of the table shows a considerable diversity in results that can not be attributed alone to the difficulties encountered in using bituminous coal. It is probable that with coke or anthracite fuel quite as great a variation would be experienced in plants of diverse sizes and operating conditions. The data in Table 17 show that in plants using 100 per cent coal no better results were obtained with good eastern gas coal than with Central District coals. In only one plant under the observation of the authors have both classes of coal been used, and here there was little apparent difference in the results with fuels from different fields, although the Central District coals operated somewhat more satisfactorily. The eastern gas coal used by this plant, while of very good grade, was of smaller size than would have been desirable, and this condition perhaps affected the results adversely. It is also quite possible that the weaker coking properties of Central District coals as compared with eastern gas coals is a consideration in favor of the former coals for this purpose. No extensive studies of the coking property of coals in relation to their values in water-gas manufacture have been made, although the indications are that such studies would give much interesting information. Statistics on plant F of Table 17 indicate that mixtures of anthracite and bituminous coals have been used with considerable success. The action of the anthracite in such mixtures is similar to that of coke; it makes the fire more penetrable to the blast, and by the interposition of lumps of noncoking fuel between the lumps of coking coal breaks up the continuity of the caking mass.

SUGGESTIONS FOR OPERATING WITH COAL FUEL.

It is impossible to formulate fixed rules for operation that will apply equally well to all conditions. The operator using coal as generator fuel for the first time will probably need to experiment a little to find the conditions that best apply to his plant. The following suggestions are presented merely as a guide to those undertaking the use of coal as generator fuel for the first time:

1. The experiments may well be begun with only 50 per cent of coal and the per cent of coal in the mixtures increased gradually from day to day as the experiments progress.

2. Select a coal of low sulphur content. This is particularly necessary when the purifying capacity is limited.

3. The coal should not be too fine, but preferably in 4 to 6 inch lumps. Very fine material should be excluded by forking the coal with the usual coke fork.

4. When operation is begun, do not make double charges of coal, for heavy charges at the start usually result in a cold generator, difficulty in bringing up the heat, and excessive smoke production.

It is better to have a deep fuel bed by making a large charge shortly before shutting down the night before; then the carburetor can be lighted and a run made before any coal is charged. This will give a quicker start, diminish the smoke, and result in a large make from the first.

5. Build up the generator fire by coal charges of normal size (the same weight as when coke is used). Make the charges at intervals of two runs until the fire is up to the normal working height—that is, just below the take-off connection; then charge at intervals of about five or six runs. Make the charges as rapidly as possible, to avoid loss of time. Heavier charges may be made with coals that do not cause serious arching and caking difficulties.

6. Proportion the up and down runs and the steam used so that the clinker will come down to the grate where it can be readily removed. The proportion can best be determined by trial. At Streator, most of the coals did best with three up runs to two down runs. Usually two successive up runs were made after charging, though occasionally alternate up and down runs seemed more satisfactory.

7. The length of the blow and of the steam run will depend upon the blast and steam available. In general, try so to proportion the blow and the run that the generator, carburetor, and superheater will attain normal working temperatures at the same time. There is frequently a tendency for the carburetor and superheater to become too hot before the generator is hot enough. This overheating of the checker chambers has been partly overcome by one or more of the following methods:

a. By allowing some gas to burn at the stack.

b. By oversteaming the generator and thereby diminishing the amount of combustible gas formed, although this cools the generator still more.

c. By overblowing the carburetor and superheater.

d. By using the blow-run cycle.

Of these, the writers believe that method *d* is the most economical and results in the largest capacity per set. If this cycle is not desired, then method *c* or method *a* seems generally the least objectionable, when conditions permit.

8. Use reduced steam and oil during the first four or five runs, while the set is being brought up to a working temperature.

9. Make the blow run, if adopted, of only sufficient length to maintain the normal heat balance in the set and to obtain the desired make of gas without an excessive oil consumption per 1,000 cubic feet.

10. *Close the carburetor and superheater blast valves before the stack cap is shut to make the blow run. Do not reverse the hot valves while*

making the blow run. Close the generator blast valve before turning on the steam to make the regular steam run.

11. Be sure that after the carburetor and superheater blast valves have been closed preparatory to making a blow run, the burned gases in the set are purged out before the stack lid is closed. The time consumed in operating the valves and closing the lid is usually sufficient for this purpose, but mechanically operated valves sometimes have closed so quickly that much burned gas was blown into the holder.

12. Make sure that the carburetor and superheater chambers are not being overblown or underblown by the secondary air blast if they remain cold when the blow-run cycle is used. If the checker chambers do not now heat properly, it will probably be necessary to increase the length of the blast period, decreasing the steaming period correspondingly. This will accomplish the desired results. Failure of the checker chambers to heat properly has been incorrectly attributed to too long a blow run, and the blow run was accordingly shortened. This, of course, is not necessary.

13. Considerably more tar is produced with coal than with coke fuel. Care should be taken to remove the tar from the gas before it reaches the purifiers. The operation of the tar extractor or shavings scrubber especially should be watched.

14. Remove the flanges on the bottom of the hot valves occasionally to clean out deposits of carbon or carbonized tar. The presence of such deposits is indicated by the failure of the valves to close tightly.

15. Leave the generator lid slightly open or "cracked" during lay-over periods. This seems to assist in heating the generator and in burning off any carbon which may have been deposited in the checkerwork of the carburetor and superheater. When the stack draft is not sufficient to draw air in through the lid opening, it is not advisable to leave this lid open unless artificial means of inducing a draft are employed, such as a steam jet in the stack.

16. Watch for sticking of the hot valves and oil-spray stems during lay-over periods. This is due to pitch deposits, and may be alleviated by occasionally smearing the stems with a mixture of lubricating oil and graphite.

17. Use a fuel spreader whenever conditions permit.

18. Make sure that green fuel does not pass through the fire with the ashes. When the up and down runs are properly proportioned as suggested in 6, there should be very little loss on this account.

19. Shut down for a few minutes after about 30 runs are made, or midway between cleans, and break up the clinker with bars. If no attempt is made to remove the clinker very little time will be consumed and the make per run will increase nearly to normal.

20. Test the oil spray occasionally and make sure it is atomizing the oil properly. It is desirable to have several oil sprays on hand so that they can be changed and cleaned frequently.

21. When an oil is used that causes considerable carbon trouble, it may be well to overblast the carburetor, thus burning off some of the deposited carbon. When a set is operated with a long lay-over period, a better way would be to draw air through the checker chambers by means of the stack draft. This can be done by removing the oil spray.

BY-PRODUCTS.

TAR.

Tar is a by-product of nearly all water-gas processes now in common use. The quality and quantity of it vary in different plants and in any given plant as the operating conditions are changed. Some of the factors that have important bearing on both the quality and the quantity of tar produced are the temperature in the checker chambers, the quality and quantity of blue gas in which the oil is cracked, the intimacy and time of contact of oil vapors with the checkering, the time and method of injecting oil in the carburetor, the kind of oil used, and the kind of fuel used.

Since gas is the main product sought and the formation of tar is looked upon as a necessary evil, the quantity of tar produced per gallon of oil used is of secondary consideration. The quality and quantity produced, when operating with a specified fuel and oil, may be said to vary as the temperature in the oil-cracking chambers varies. Excessively high temperatures in these chambers are favorable to the production of lampblack or naphthalene and the formation of less tar. On the other hand, low temperatures favor the formation of an increased amount of tar. In other words, the oil is not thoroughly cracked and fixed at low temperatures, and an increased per cent of it is converted into tar, while at excessively high temperatures the oil is said to be overcracked, more gas being made per gallon of oil used, simultaneous with the production of more carbon and less tar.

When oil is cracked, as in a water-gas set, the nature and amount of the different products formed depend to a considerable extent on the atmospheres in which the oil is cracked. In some atmospheres the per cent of tar formed is increased and in others it is decreased. For example, when oil is cracked in a blue gas containing excess steam, the production of tar and gas is increased, while the amount of carbon formed is decreased.

The time and the intimacy of contact likewise affect the quantity and nature of the products resulting from oil cracking. An increase in the total time that the oil vapors are in contact with the hot brick tends to decrease the per cent of tar formed and to increase the per cent of carbon.

The method and time of injecting the oil into the carburetor governs the concentration of the oil vapors and the time of contact of the oil vapors with the bricks, and therefore directly affects the amount of tar formed. If the oil is injected too rapidly to be fixed properly an excessive formation of tar results. Even though the rate of oil input is suitable, an inefficient oil spray may result in so poor a distribution of oil in the carburetor that the oil is not properly cracked. Under such circumstances an increased amount of tar would be produced.

Different oils, when subjected to the same heat temperature or cracking process, produce different amounts of tar. One oil may produce 15 per cent of tar while another may produce 25 per cent under the same conditions.

The fuel used also regulates to some extent the amount of tar formed under a given set of conditions. This is true even if the effect on oil cracking caused by a difference in the quality of blue gas produced is left out of consideration.

When coke is used as generator fuel, no appreciable amount of tar is produced during the steam run, but when a high volatile bituminous coal is used in place of coke, tar is produced in the generator. The green fuel on top of the fuel bed is being distilled during the run, the tarry matter passes on with the similar products from the oil cracking, and the result is an increase in the total amount of tar produced.

The quality of the tar produced is frequently of more importance than the quantity. This is apparent when consideration is given to the fact that sometimes a tar is produced with an exceedingly high free carbon and water content. Such a tar can not be readily separated from the water by ordinary settling and will not usually produce as valuable products as a tar with a low free carbon content.

A discussion of the influence of each of the variables affecting the quality and the value of water-gas tar will not be attempted in this paper, although the effect of a change from coke to coal fuel seems to be worthy of special mention.

It has been observed that the yield of tar figured as tar per gallon of oil used is considerably increased when a high-volatile bituminous coal is used in place of coke as generator fuel and the physical and chemical nature of the tar is materially altered. Enough information has not been obtained to say definitely how much tar can be produced when a particular coal is used. Obviously, the operating variables as well as the daily operating time influence the volume and properties of the tar. The indications are that the volume of tar may be increased as much as 25 per cent when a change to coal fuel is made. Tar so produced is heavy and viscous, with the appearance of coal tar rather than of ordinary water-gas tar. The properties of water-gas tars are to be studied by one of the authors of this bulletin. A few analyses are given in Table 18, which follows.

Sample 1 was obtained when coal was used as fuel without the blow run. The temperatures in the carburetor and the superheater were excessive and it is likely that the high percentage of free carbon in the tar can be attributed to this cause.

Sample 2 was obtained with the blow run, the carburetor and superheater temperatures being normal.

TABLE 18.—*Differences in the composition of water-gas tars.*

	Sample 1.	Sample 2.	Sample 3.
Fuel used	Bituminous coal.	Bituminous coal.	Coke.
Specific gravity at 15.5° C.	1.17	1.16	1.055
Free carbon ... per cent	9.14	4.85	Trace.
Moisture ... do	8.40	3.00	
Distillation of dry tar.			
Up to 110° C ... per cent	0.0	0.0	0.2
110° to 170° C ... do	.8	.0	1.2
170° to 235° C ... do	4.3	1.6	15.7
235 to 270° C ... do	9.8	7.2	18.7
270 to 300° C ... do	15.3	9.1	20.6
Residue ... do	(brittle) 69.4	82.0	(brittle) 38.8
Undetermined ... do	.4	.1	4.8
Total ... do	100.0	100.0	100.0
Tar acids	Trace	0.0	

The distillations were made in a 500-c. c. glass distillation flask, with the thermometer bulb at the offtake arm.

AMMONIA.

Ammonia is a by-product in coal-gas manufacture, but is not usually present to any extent in water gas. This is particularly true of water gas made from coke fuel. If bituminous coal is used in the generator, it may be anticipated that some ammonia would be formed during the run by the distillation of the green coal. Steam distillation under the prevailing temperature conditions might also be expected to augment ammonia production. However, consideration of the fact that only a small amount of fuel is consumed per 1,000 feet during the run leads to the conclusion that the quantity of ammonia produced would not be very great. A test for free ammonia (NH_3) in the blue gas sampled at the generator lid showed 45 grains of NH_3 per 100 cubic feet of blue gas made, an amount roughly equivalent to 36 grains of NH_3 per 100 cubic feet of finished gas. A calculation on the basis of NH_3 per ton of coal used in the generator indicates that 2.6 pounds of NH_3 are obtained per ton of coal. Part of this ammonia is decomposed during the passage of the gas through the checker chambers. The gas at the outlet of the superheater, before the wash box, contained only 25 grains of NH_3 per 100 cubic feet of finished gas, the equivalent of 1.8 pounds of NH_3 per ton of coal consumed. The loss in passing through the checker chambers was 30.8 per cent.

The amount present in any particular plant with a given fuel and specified operating conditions can best be determined by analyses of each individual gas. The problem of recovery is an economic as well as a mechanical and chemical one. Fresh water was used in all the scrubbing apparatus and in the wash box during the course of the Streator experiments, and there was no attempt made to recover the ammonia produced.

DESIGN OF WATER-GAS APPARATUS.

Present-day water-gas apparatus has been designed for use with fuel that contains only a small percentage of volatile combustible and a high proportion of fixed carbon. Hence the same fuel and oil efficiencies would not be obtained with the same operating methods when high-volatile bituminous coals are substituted for high-carbon, low-volatile fuels.

Although an operating method has been worked out, as discussed in this bulletin, whereby some of the difficulties encountered when high-volatile fuels are used can be mitigated, the indications are that a set might be so designed that a greater oil and fuel economy could be obtained. A specially designed set of this type would be advantageous where local conditions necessitate the use of coal instead of coke as generator fuel. However, such a set has not yet been designed and its development and perfection are still problems for additional research.

ECONOMIC SIGNIFICANCE OF THE USE OF BITUMINOUS COAL AS GENERATOR FUEL.

Although a number of plants are now operating successfully with bituminous coal as generator fuel, some of them first resorted to this practice in anticipation of a war measure requiring them to do so. The substantial saving made with this fuel, which may be as high as 8 cents per 1,000 feet, is great enough to warrant other companies giving the matter serious consideration. The saving is due chiefly to the difference in price of coal and coke and to the decreased amount of oil used per 1,000 cubic feet of gas made. Since the prices of coal, coke, and oil are different in various parts of the country, the saving to be realized can only be determined when these conditions are known. However, it is very generally true that coke costs considerably more per ton than coal, and in addition a good grade of coke is only obtainable at many plants by shipment from a considerable distance.

SULPHUR CONTENT AS A LIMITING FACTOR.

A large proportion of the total coal supply of the United States contains a rather high per cent of sulphur. When such coals are used as generator fuel, more sulphur passes into the unpurified gas and the amount of it seems to vary as the per cent of total sulphur in the coal varies. This means an added duty for the purifiers, with a resultant increase in the cost of the finished gas, if the sulphur is not recovered as a by-product. In some plants where the purifying capacity is limited an increased amount of sulphur in the raw gas offers a serious problem for the engineer. High-sulphur coals are very often lower in price delivered than low-sulphur coals and frequently have better gas-making properties as well. Although it is natural to specify low-sulphur coals from a desire to keep operating expenses as low as possible, the advantages to be gained by utilizing coals of higher sulphur content may sometimes be great enough to warrant increasing the purifying capacity.

USE OF COALS FROM OTHER DISTRICTS AS GENERATOR FUEL.

The authors' experiments were limited to Central District coals, therefore figures can not be given for the economies obtainable with other high-volatile coals. Many of them would, no doubt, answer equally well for this purpose. Some trouble may be anticipated, however, with coals that disintegrate when heated.

SUMMARY AND CONCLUSIONS.

The results at the Streator plant and in other plants where bituminous coal is in use as generator fuel seem to justify the following conclusions:

1. High volatile bituminous fuel can be used efficiently in the manufacture of water gas.
2. An oil economy can be realized when bituminous coal is used as generator fuel, due to the increased value of the blue gas occasioned by the presence of some of the volatile matter of the coal.
3. When coal fuel is used, it is not necessary to operate with a relatively cold generator, thereby materially reducing the make.
4. Operating methods can be so adjusted that the capacity when coal is used with the present apparatus can be made to approach that attained with a good grade of coke, and to equal or surpass that attained with an inferior coke. The blow-run method of operating is one example of such adjustment.

5. The reduced capacity frequently noted when bituminous coal (coking coal) is used in the generator is in part due to the resistance to the air blast occasioned chiefly by the coking and matting of the fuel.

6. The resistance to the passage of air through the fire is materially decreased by the uniform admixture of coke with the coal.

7. When mixtures of coal and coke containing more than 50 per cent of coal are used, there seems to be a definite mixture that is favorable for a maximum make. The amounts may vary with different coals, but for those used in the Streator experiments the most satisfactory mixture was 70 per cent coal and 30 per cent coke, without blow run.

8. When the blow run is employed with the 70–30 mixture of coal and coke, the make is further increased.

9. When the blow run is used with a fuel mixture containing 70 per cent coal and 30 per cent coke, the oil used per 1,000 feet was not noticeably increased over the amount used with 100 per cent coal.

10. The production of smoke which is associated by some operators with the use of bituminous coal, can be almost if not entirely eliminated by slight modification of the operating procedure.

11. Indications are that, if bituminous coal is used, with careful operation the amount of generator fuel per 1,000 cubic feet of gas made need not be very much greater than with coke fuel of approximately the same heating value. Plants are now operating consistently with a consumption of 37 to 40 pounds of Central District coal per 1,000 feet that previously used 33 to 37 pounds of coke to produce the same amount of gas.

12. The utilization of coal in place of coke as generator fuel, when shipment from distant points is to be avoided, conserves the transportation facilities of the country.

PUBLICATIONS ON GAS PRODUCERS AND INDUSTRIAL GASES.

A limited supply of the following publications of the Bureau of Mines has been printed. Requests for publications should be addressed to the Director, Bureau of Mines.

The Bureau of Mines issues a list showing all its publications available for free distribution as well as those obtainable only from the Superintendent of Documents, Government Printing Office, on payment of the cost of printing. Interested persons should apply to the Director, Bureau of Mines, for a copy of the latest list.

PUBLICATIONS AVAILABLE FOR FREE DISTRIBUTION.

TECHNICAL PAPER 9. The status of the gas producer and of the internal-combustion engine in the utilization of fuels, by R. H. Fernald. 1912. 42 pp., 6 figs.

TECHNICAL PAPER 106. Asphyxiation from blast-furnace gas, by F. H. Willcox. 1916. 79 pp., 8 pls., 11 figs.

Technical Paper 112. The explosibility of acetylene, by G. A. Burrell and G. G. Oberfell. 1915. 15 pp.

Technical Paper 150. Limits of complete inflammability of mixtures of mine gases and of industrial gases with air, by G. A. Burrell and A. W. Gauger. 1917. 13 pp., 2 figs.

Technical Paper 185. Use of the interferometer in gas analysis, by F. M. Seibert and W. C. Harpster. 1918. 18 pp., 1 pl., 5 figs. 5 cents.

Technical Paper 216. Vitiation of garage air by automobile exhaust gases, by G. A. Burrell and A. W. Gauger, 1919. 12 pp.

Technical Paper 246. Water-gas apparatus and Central District coal as generator fuel, by W. W. Odell. 1921. 28 pp., 1 pl., 1 fig.

Technical Paper 267. Stenches for detecting leakage of blue water gas and natural gas, by S. H. Katz and V. C. Allison. 1920. 22 pp., 2 figs.

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INDEX.

A — Page.

- Adams, L. H., work cited, 5, 6
- Air blasting, reactions during, 8
- Air purge, procedure for, 57, 58
- Ammonia, as by-product, production of, 85, 86
- Arching, in generator, control of, 56, 57
- Ash formation, effect of bituminous fuel on, 37

B.

- Bituminous coal, advantages of, 3
  - limitations of, 3
- Blast gas, composition of, 35
  - effect of quantity of steam on, figure showing, 39
  - quality of, 34–36
- Blow-run gas, analyses of, 68
- Blow-run method, description of, 62
  - effect of, on capacity, 72–73
    - on carburetor, 66–68
    - on composition of gas, 64–66
    - on fuel economy, 68–71
    - on generator conditions, 62–64
    - on oil economy, 68–71
    - on superheater, 66–68
    - table showing, 67
  - use of coal and coke mixtures with, 73–75
  - variation in gas made by, curve showing, 74
- Blue gas, analyses of, 35
  - produced between coalings, analysis of, 63
  - produced with blow-run cycle, analysis of, 63
  - produced without blow-run cycle, analysis of, 63
  - quality of, 34–36
- Blue gas. *See also* Water gas.
- Boudouard, O., work cited, 32

C.

- Cady, G. H., work cited, 62
- Caking, control of, 42–43, 56
- Capacity, reduction of, with coal fuel, 45–46, 57
- Carbon dioxide, in gas, proportion of, 6
  - during blow-run period, curve showing, 9
- Carbon monoxide, in gas, proportion of, 6
  - rate of formation of, from carbon dioxide and coke, table showing, 6
- Carburetor, reactions in, 12
- Central District coals. *See* Clinton County, Ind.; Franklin County, Ill.; La Salle County, Ill.; Perry County, Ill.; Sullivan County, Ind.; Williamson County, Ill.
- Checker brick, condition of, importance of, 16–17
  - flue arrangement, figure showing, 18
  - intimacy of contact with, importance of, 17–18
  - spacing of, effect on velocity of gas, 20
    - effect on internal resistance, 20
    - importance of, 16–17
  - staggered, figure showing, 18
  - temperature of, regulation of, 15–16
  - time of contact with, 18–19

Page.

- Checker chambers, deposits in, 36
  - effect of bituminous coal on, 36
- Checkering, effect on temperature of gases made, 19
  - effect on temperature of stack gases, 19–20
- Clement, J. K., work cited, 5, 6
- Clinker, control of, 43, 60–61
  - effect of bituminous coal on, 37
- Clinton County, Ind., coal from, results with, 78–79
- Coal, bituminous, as generator fuel, advantages of, 87–88
  - operation with, suggestions on, 80–83
    - requisites for, 61
    - results with, 78–80
      - table showing, 78–79
    - savings by, 85–86
  - percentage of, effect of, curve showing, 56
  - properties of, 33
  - size of, effect of, 32
  - surface exposed, compared with coke, 32
  - use of, effect on heat balance, 36
- Coal and coke, mixtures of, experiments with, 54–56
  - table showing, 55
- Coke, properties of, 33
  - retort, results with, 74–75
- Coking properties, effect of, 33
- Cycle, operating, determination of, 39–41

D.

- Downing, R. C., work cited, 20, 31
- Down runs, advantages of, 29

F.

- Fire, cleaning of, importance of, 29
- Franklin County, Ill., coal from, analysis of, 76
  - results with, 74–75, 77, 78–79
  - consumption of, 75
  - possible economies in use of, 46
- Fuel spreader, figure showing, 44

G.

- Gas, carburetion of, 30–32
- Gas, finished, made by blow-run method, analysis of, 65
  - made without blow-run method, analysis of, 65
  - leaving generator, temperature of, 12
  - sampling of, apparatus for, 51–52
    - figure showing, 51
- Gas makers, cooperation with, 53–54
- Gas oil, grading of, by B. t. u. efficiency, 13
  - by Peoples' Gas Light Co., 14
- Generator, air blast in, conditions governing, 24
  - fuel bed of, condition of, 26
    - depth of, 26
  - hot, maintenance of, 23
  - operating cycle in, election of, 27–29
  - steam run, duration of, 24–26
  - *See also* Arching; Caking; Clinker; Superheater.

Page.
Generator gas, analyses of 57, 58

H.

Harlan County, Ky., coal from, results with 78–79
Harper, R. P., work cited 22
Harries, —, work cited 4
Haskins, C. N., work cited 5, 6
Heat, losses of, during furnace operation 9
Heat balance, effect of bituminous fuel on 36
  maintenance of 37–41
Humphreys, N. H., work cited 12

I.

Indianapolis oven coke, results with 74–75

L.

La Salle County, Ill., coal from, tests of 76

O.

Oil, cracking of, effect of bituminous coal on 36
    effect of pressure on 21–22
    efficiency of, with coal and coke fuel 71–72
      table showing 72
    essentials for 15–22
    products formed during 13
  kind of, effect of 13
  possible economies in use of 46
  quality of, effect on yield 21
Oil-cracking efficiency, effect of temperature on, curve showing 31
  effect of time of contact on, curve showing 31
Oil spraying, efficiency of, effect of 22

P.

Perry County, Ill., coal from, analysis of 76
    results with 74–75, 77, 78–79
Pohlman, E. F., work cited 20
Public Service Co. of Northern Illinois, acknowledgement to 2
Purifying process, effect of bituminous coal on 37

R.

Rittman, W. F., work cited 16, 21

S.

Page.
Smoke production, effect of bituminous coal on 36–37
  prevention of 58–60
Steam, decomposition by charcoal, table showing 5
Streator plant, description of 47–52
  experiments at, procedure for 52–61
    results of 75–78
  gas analysis at, apparatus for 50–51
    methods for 50–51
  preparation of, for tests 49–50
Sullivan County, Ill., coal from, tests of 76
Sulphur, in coal, percentage of 77
    curve showing 78
    effect of 87
Superheater, reactions in 12

T.

Tar, as by-product, production of 83–85

U.

Up runs, advantages of 29

V.

Valves, operation of, lost time from, figure showing 28
  sticking of, prevention of 44–45
Virginia, bituminous coal from, results with 78–79

W.

Water gas, quality of, effect on finished product 20
  uncarbureted, composition of 3
  See also Blue gas.
Water-gas apparatus, design of 86
Water-gas generator, reactions in 3
Water-gas plants, operating variables of, list of 22
  practice at, table showing 47
Water-gas process, by-products of. *See* Ammonia; Tar.
Water vapor, decomposition of, table showing 4
Williamson County, Ill., coal from, analysis of 76

○

O